CLIMATE MODELS
CONFIDENCE, OR CONFIDENCE GAME?

Stephen E. Schwartz

BROOKHAVEN NATIONAL LABORATORY

Upton NY

NCSL
NATIONAL CONFERENCE of STATE LEGISLATURES

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www.ecd.bnl.gov/steve

OBJECTIVES OF THIS TALK

Present overview of Earth's climate and climate change.

Identify important features of the climate system that we know and understand.

Identify important features of the climate system that we do ***not*** know or understand well.

Distinguish different kinds of climate models. Compare and contrast. Speak to their utility and their shortcomings.

Identify some of the implications of present understanding for decision-making about climate.

Leave you with some take-home messages.

STATEMENTS ABOUT MODELS

All models are wrong; some are useful.

– George E. P. Box

Models tell us the consequences of what we know or assume.

We can learn a lot from models – about what we know and about what we do not know.

CLIMATE MODELS

In what ways might they be useful?

*Decision making about **mitigation**: Controlling carbon dioxide emissions; formulating energy policy.*

*Assessing **impacts and vulnerabilities**.*

*Planning **adaptation** to future climate change.*

GLOBAL CLIMATE MODELS

Provide ***spatially and temporally resolved representation*** of the processes controlling transport of energy and matter in the ***atmosphere***, ***oceans***, and ***cryosphere***. Extended to include ***biosphere***.

Provide ***detailed description*** of change in temperature, cloudiness, solar irradiance, precipitation, etc., that would result from any projected change in atmospheric composition.

Accuracy depends on accurate representation of individual processes.

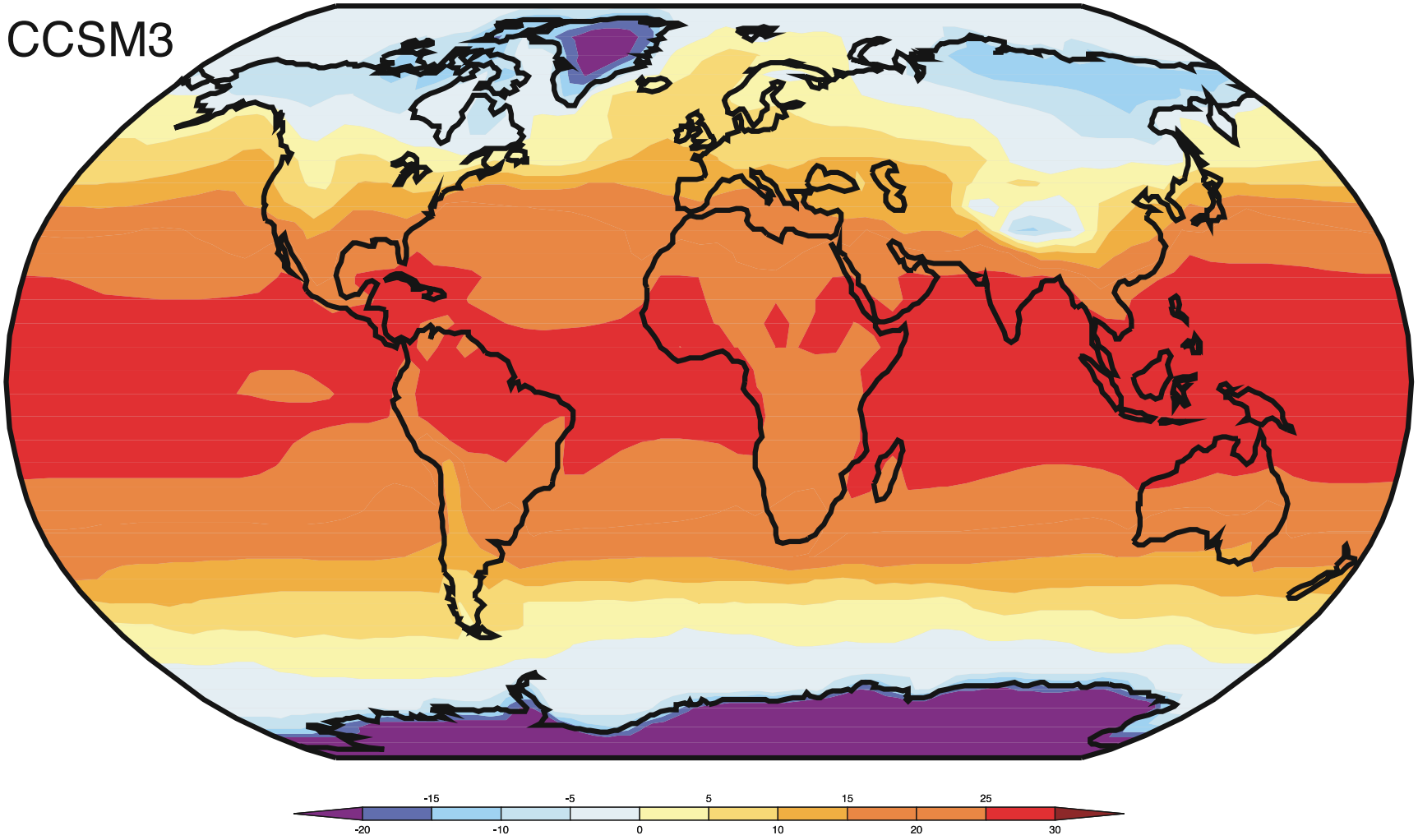
Accuracy must be evaluated by comparison with observations. Accurate representation of ***present climate*** or ***past climate change*** does not imply accuracy in representing ***future climate change***.

Allow examination of the consequences of representation of ***specific processes***. Identify sensitive processes. Identify where ***improved scientific understanding*** is needed.

Complex, arcane, non-transparent.

ANNUAL MEAN SURFACE TEMPERATURE

Calculated with Global Climate Model

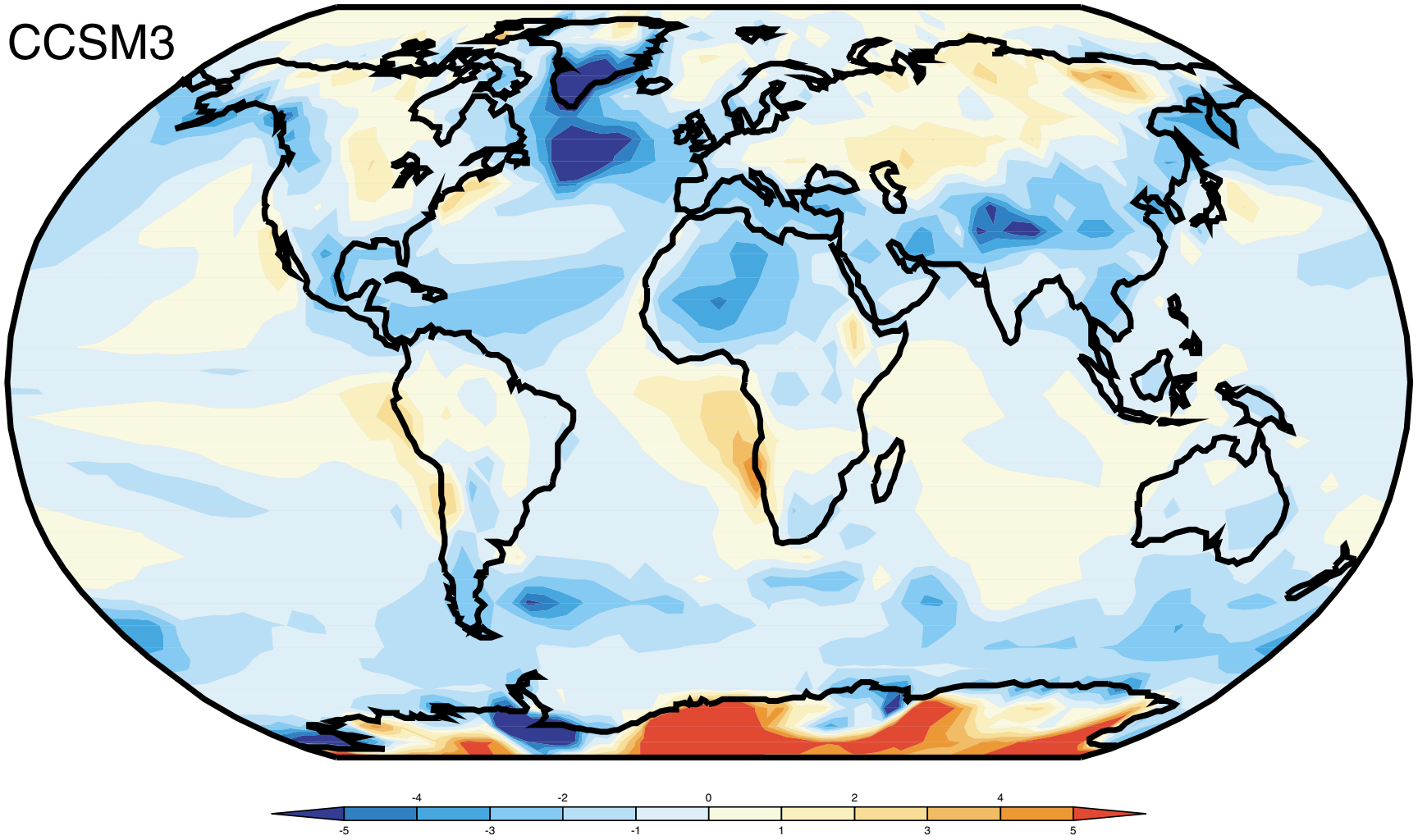


IPCC, 2007

Model output is richly detailed. Overall pattern is quite good, given that ***the entire climate system is modeled from first principles***.

ANNUAL MEAN SURFACE TEMPERATURE

Difference from observations, calculated with Global Climate Model

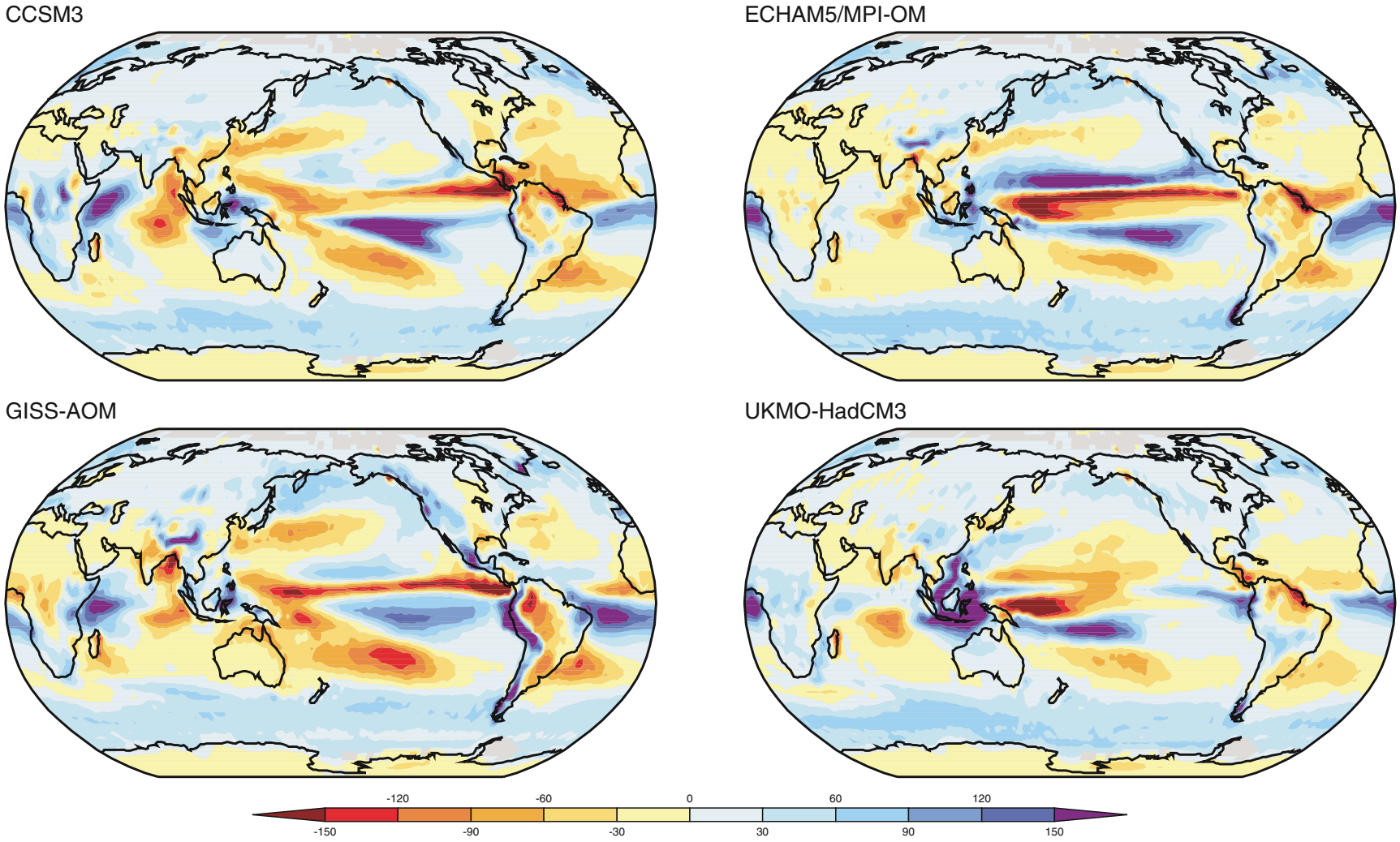


IPCC, 2007

Accuracy is quite good at most locations, but departures from observations even of 1 or 2 degrees C are climatologically significant.

ANNUAL MEAN PRECIPITATION

Difference from observations, calculated with Global Climate Models



IPCC, 2007

Departure from observations and model-to-model differences are substantial in some locations. (30 cm = 12 inches.)

ENERGY BALANCE MODELS

Whole-Earth models – or vertically or latitudinally resolved.

Transparent, readily understood, dependence on parameters readily examined and understood.

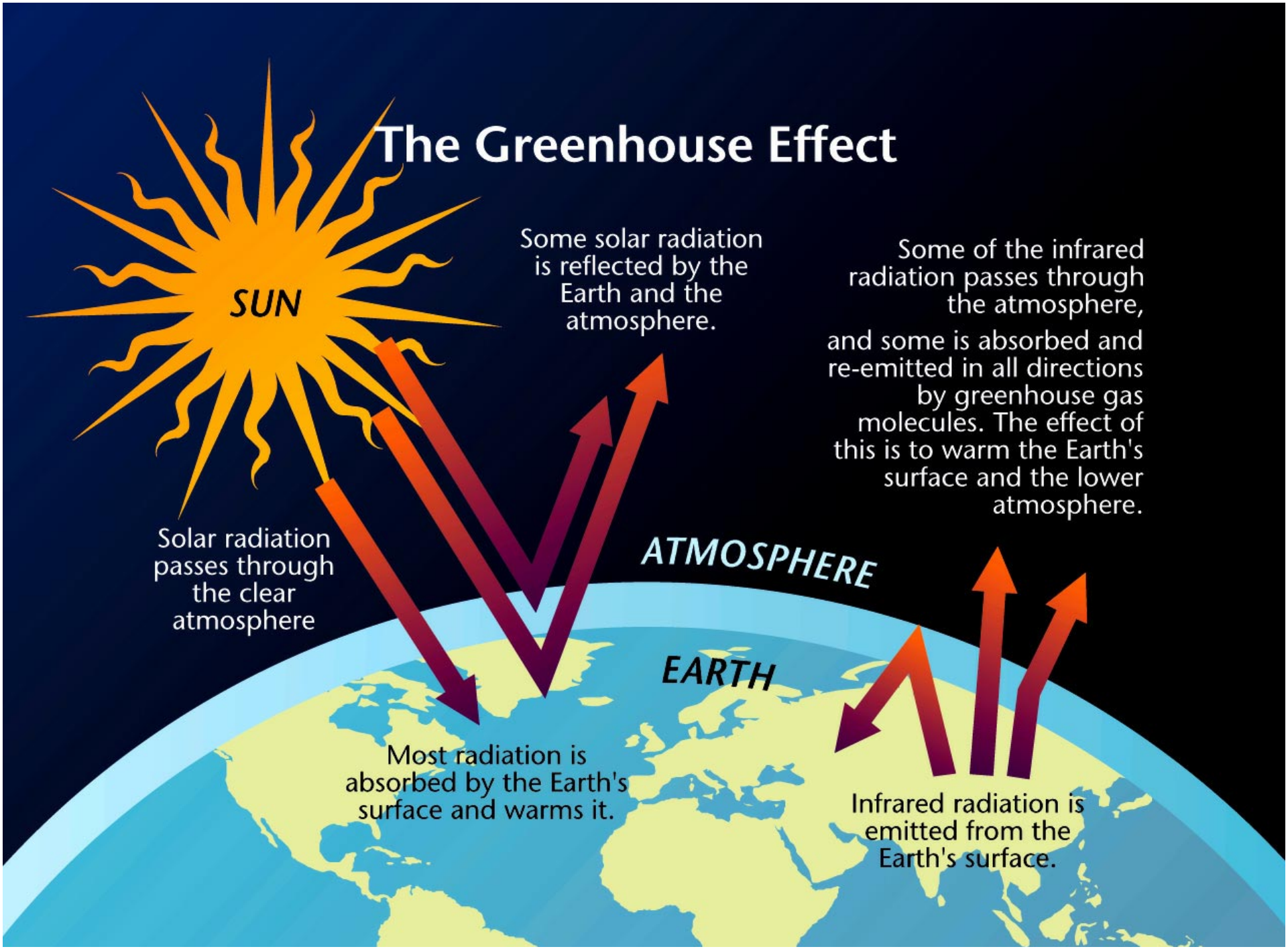
$$\Delta T = S \times \Delta F$$

Change in Global Temperature

$$= \textit{Climate Sensitivity} \times \textit{Change in Radiative Flux}$$

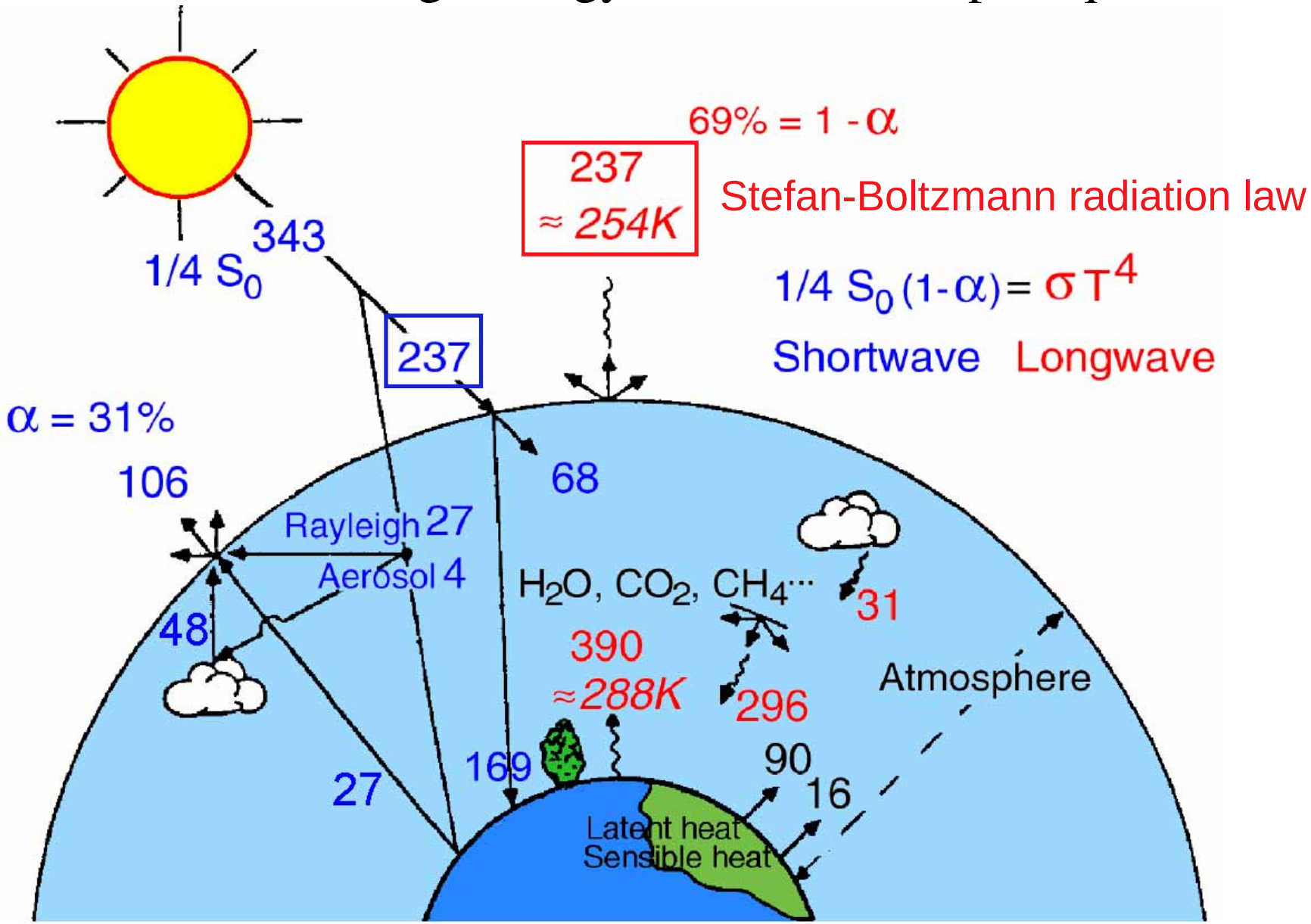
Require observational inputs not available or not sufficiently accurate: Temperature change, Changes in atmospheric radiation, Radiation measurement from satellite, Ocean heat content change, Poleward heat flux.

Do not yield important spatial detail, changes in precipitation, etc.


The Greenhouse Effect
SUN
Some solar radiation is reflected by the Earth and the atmosphere.
Some of the infrared radiation passes through the atmosphere,
and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.
Solar radiation passes through the clear atmosphere
ATMOSPHERE
EARTH
Most radiation is absorbed by the Earth's surface and warms it.
Infrared radiation is emitted from the Earth's surface.

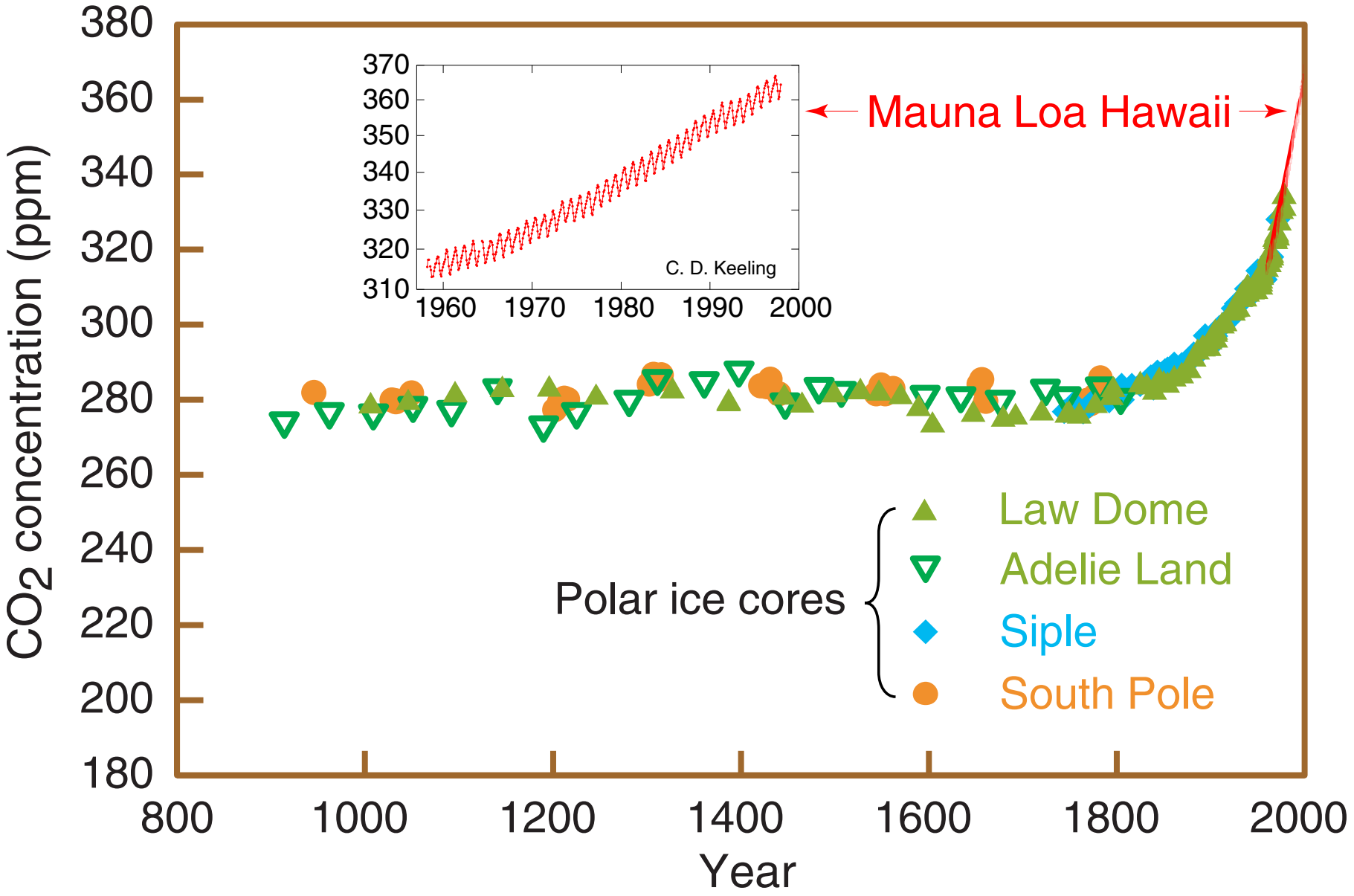
GLOBAL ENERGY BALANCE

Global and annual average energy fluxes in watts per square meter



Schwartz, 1996, modified from Ramanathan, 1987

ATMOSPHERIC CARBON DIOXIDE IS INCREASING

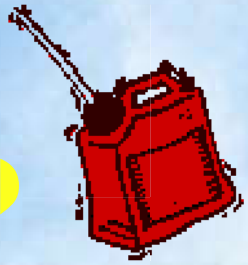


Global carbon dioxide concentration over the last thousand years

HOW MUCH CARBON IS IN A GALLON OF GASOLINE?

1 lb?

2 lbs?



3 lbs!?

5 lbs!?!

All of this carbon goes into the atmosphere as carbon dioxide when you burn the gasoline in your car.

RADIATIVE FORCING

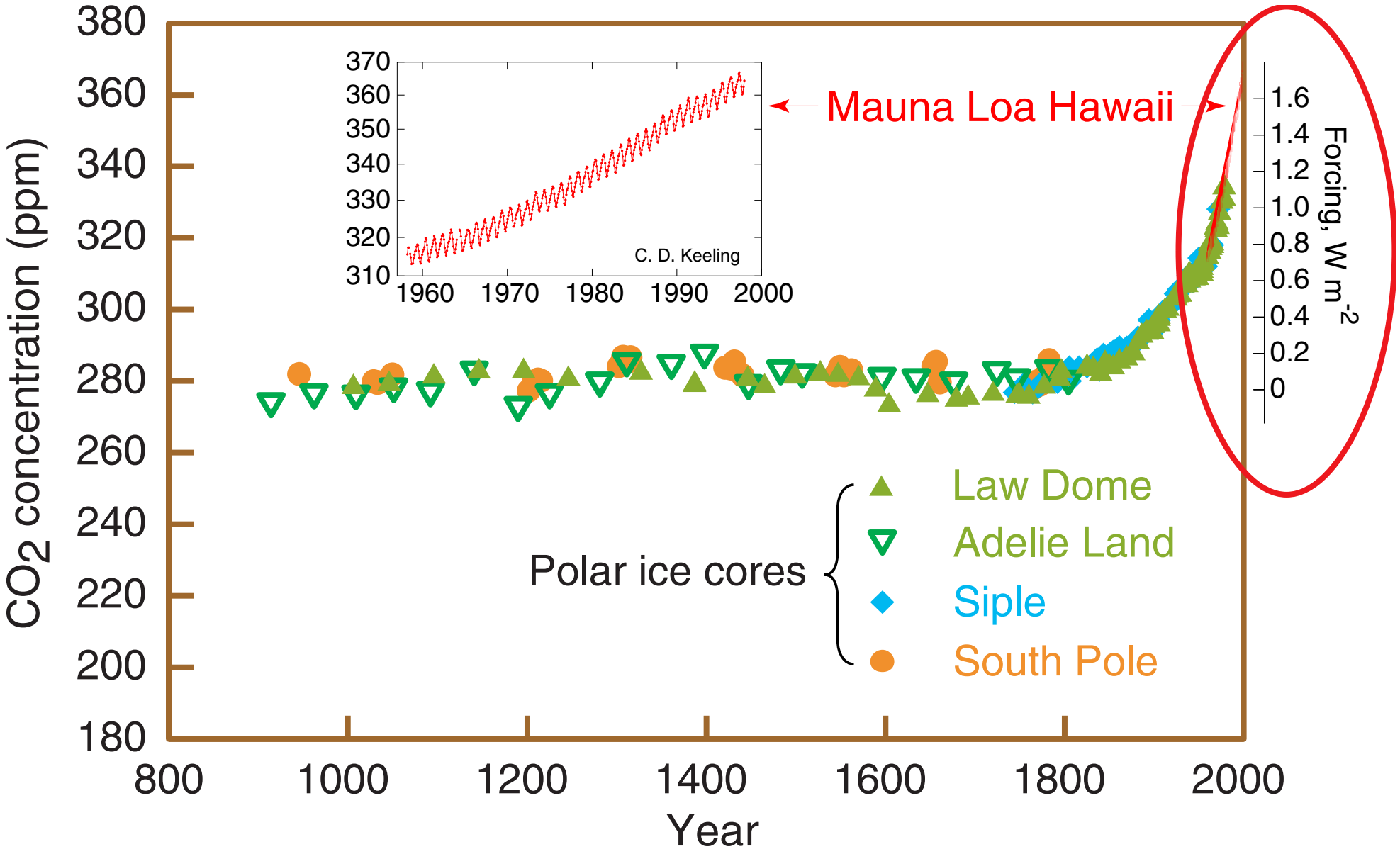
A ***change*** in a radiative flux term in Earth's radiation budget, ΔF, W m^{-2}.

Working hypothesis:

On a global basis radiative forcings are additive and fungible.

- This hypothesis is fundamental to the radiative forcing concept.
- This hypothesis underlies much of the assessment of climate change over the industrial period.

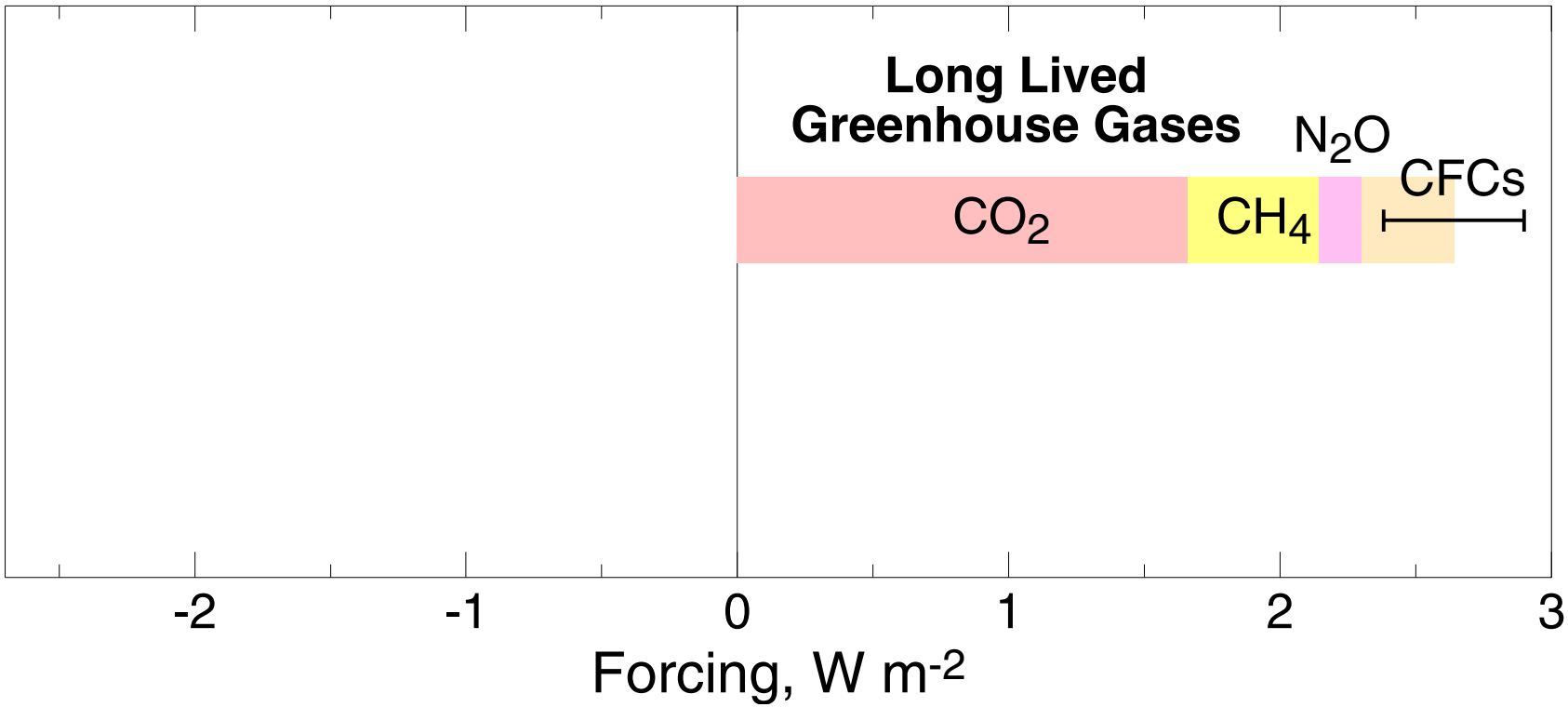
ATMOSPHERIC CARBON DIOXIDE IS INCREASING



Global carbon dioxide concentration and infrared radiative forcing over the last thousand years

CLIMATE FORCINGS OVER THE INDUSTRIAL PERIOD

Extracted from IPCC AR4 (2007)

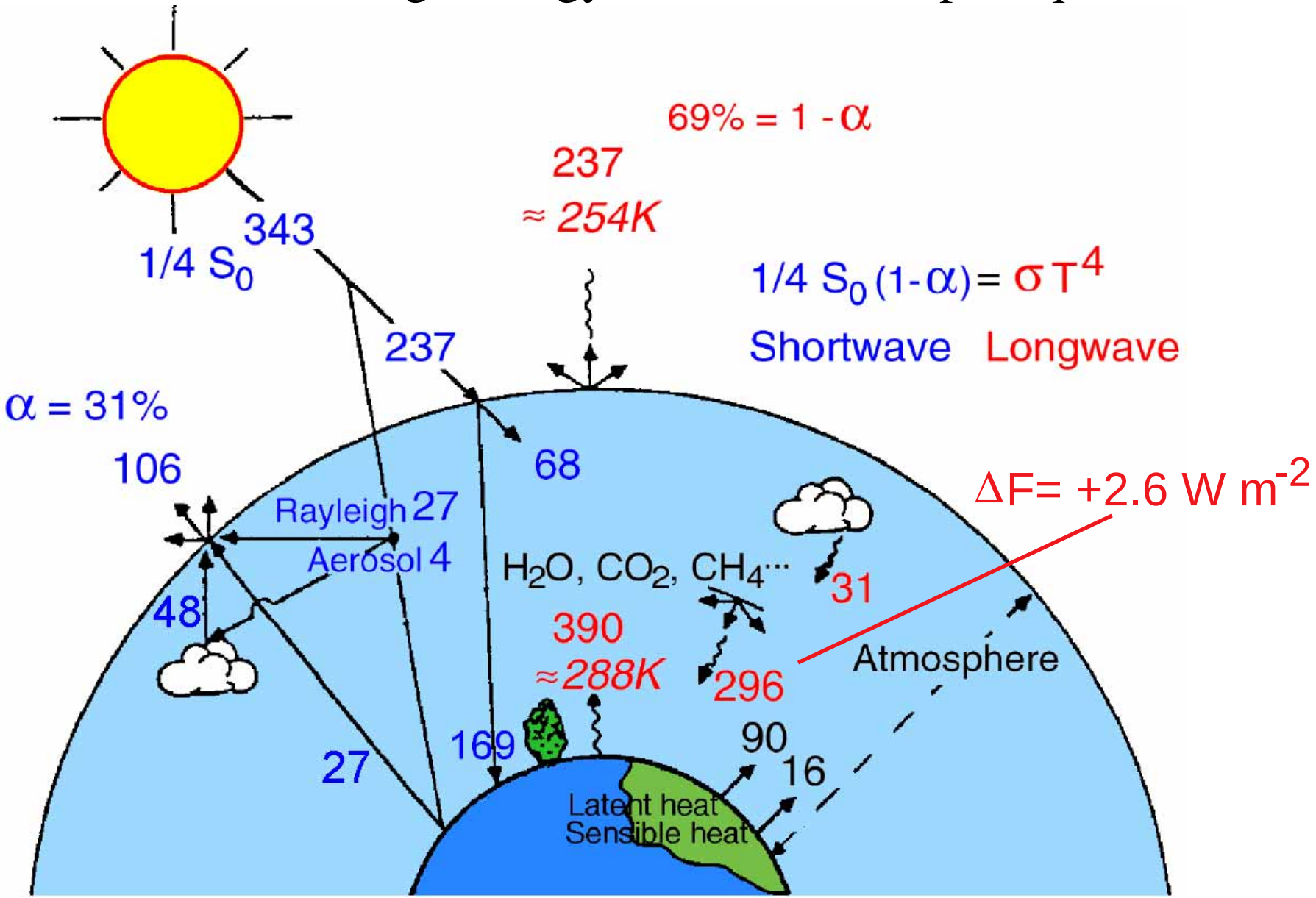


Greenhouse gas forcing is considered accurately known.

Gases are uniformly distributed; radiation transfer is well understood.

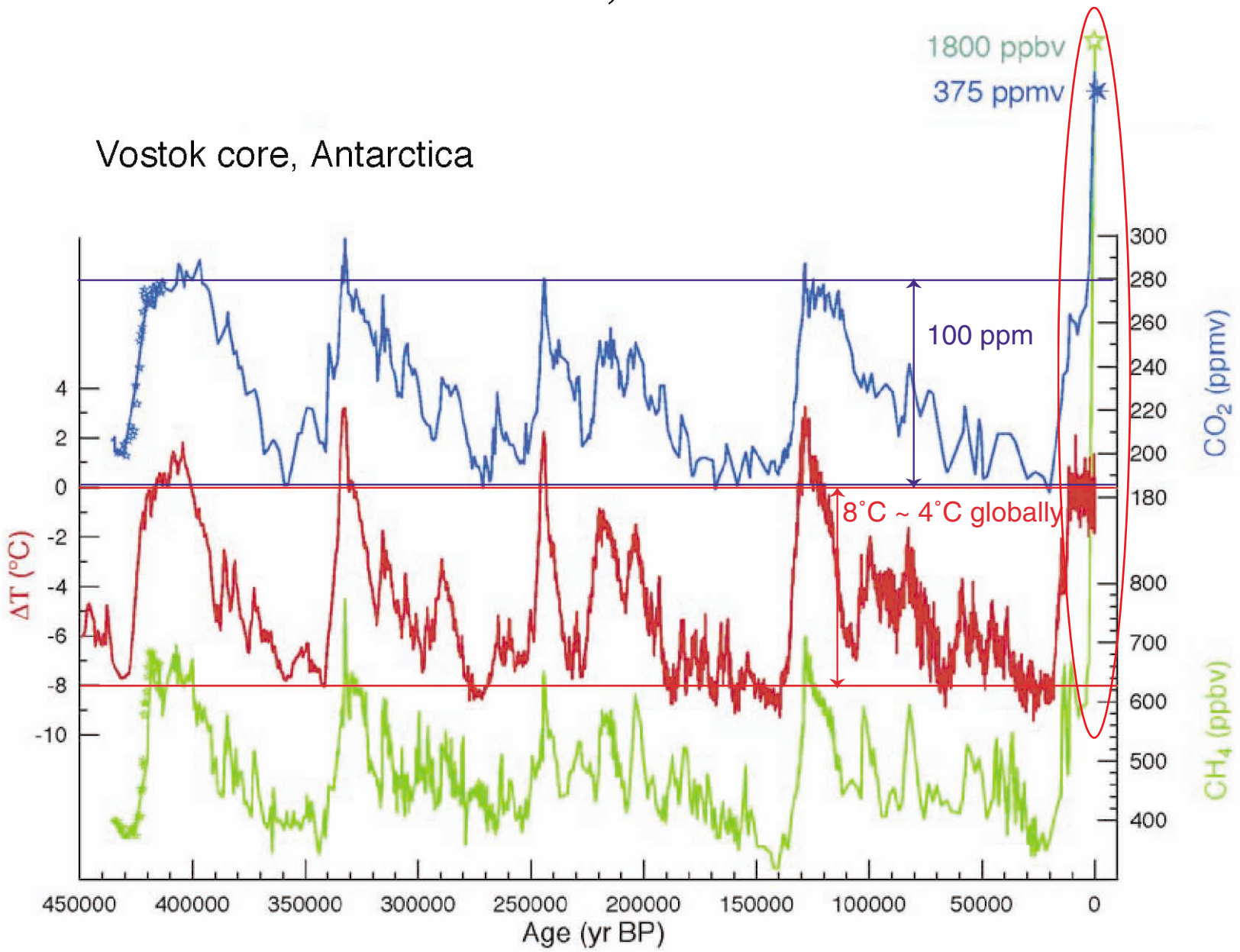
GLOBAL ENERGY BALANCE

Global and annual average energy fluxes in watts per square meter



Schwartz, 1996, modified from Ramanathan, 1987

GREENHOUSE GASES AND TEMPERATURE OVER 450,000 YEARS

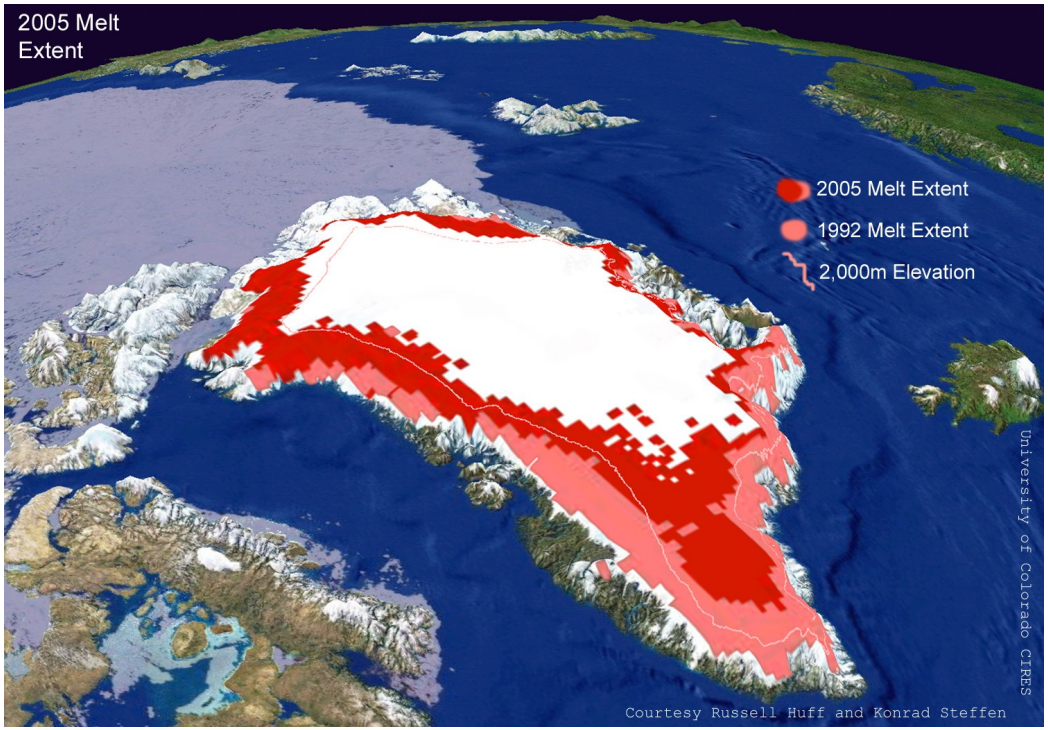


Modified from Petit et al., Nature, 1999

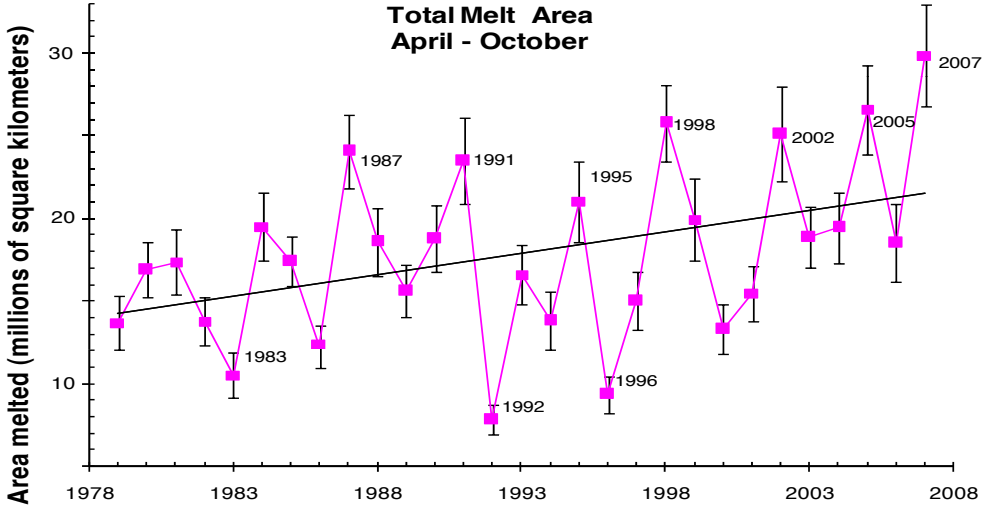
MELTING OF GREENLAND ICE CAP

Satellite determination of maximum extent of glacial melt

NASA



Complete melt of the Greenland ice sheet would raise the level of the global ocean 23 feet.



Steffen & Huff , Univ. Colo., 2005

CLIMATE RESPONSE
AND
CLIMATE SENSITIVITY

CLIMATE RESPONSE

The ***change*** in global and annual mean temperature, ΔT, K, resulting from a given radiative forcing.

Working hypothesis:

The change in global mean temperature is proportional to the forcing, but independent of its nature and spatial distribution.

$$\Delta T = S\,\Delta F$$

CLIMATE SENSITIVITY

The ***change*** in global and annual mean temperature per unit forcing, S, K/(W m^{-2}),

$$S = \Delta T/\Delta F.$$

Climate sensitivity is not accurately known and is the objective of much current research on climate change.

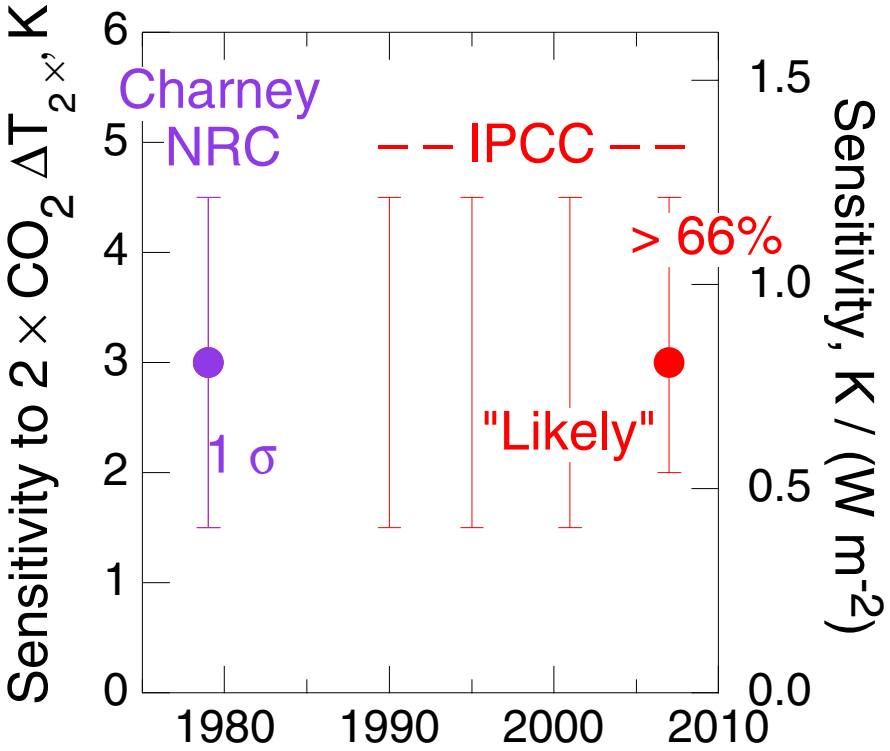
Climate sensitivity is often expressed as the temperature for doubled CO_2 concentration $\Delta T_{2\times}$.

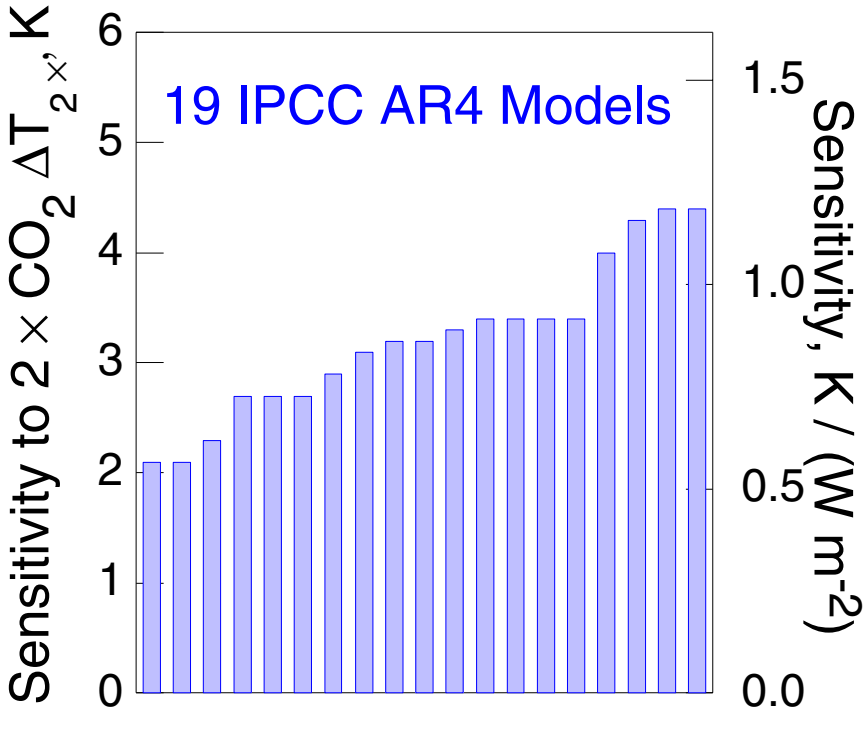
$$\Delta T_{2\times} = S\Delta F_{2\times}$$

$$\Delta F_{2\times} \approx 3.7 \text{ W m}^{-2}$$

ESTIMATES OF EARTH'S CLIMATE SENSITIVITY AND ASSOCIATED UNCERTAINTY

Major national and international assessments and current climate models



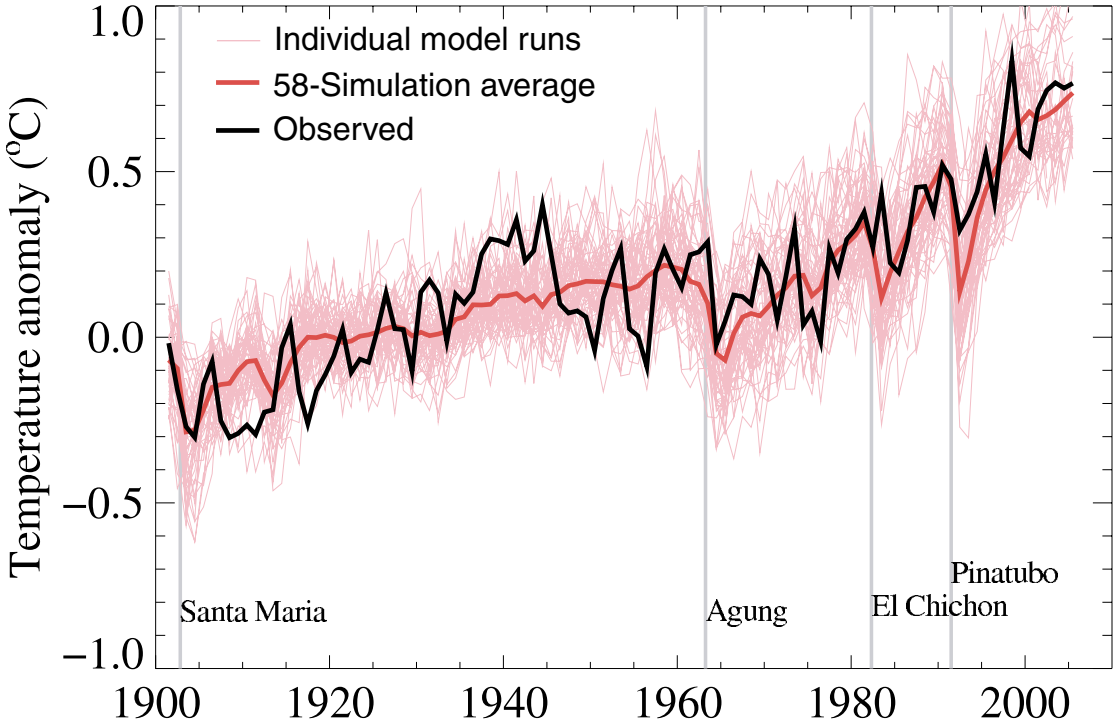


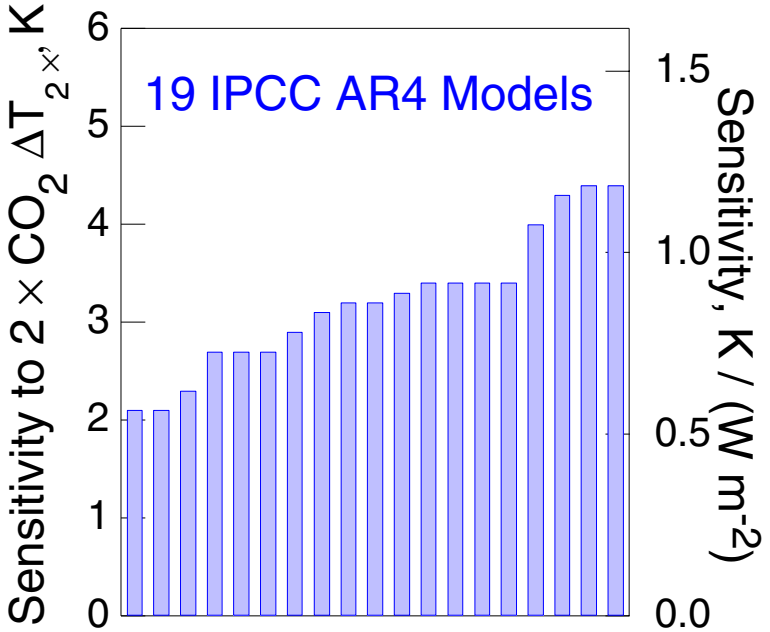
Current estimates of Earth's climate sensitivity are centered about a CO_2 doubling temperature $\Delta T_{2\times} = 3$ K, but with substantial uncertainty.

Range of sensitivities of current models roughly coincides with IPCC "likely" range.

TOO ROSY A PICTURE?

58 model runs with 14 Global Climate Models





- Simulations that incorporate anthropogenic forcings, including increasing greenhouse gas concentrations and the effects of aerosols, and that also incorporate natural external forcings provide a ***consistent explanation of the observed temperature record***.
- These simulations used models with ***different climate sensitivities, rates of ocean heat uptake and magnitudes and types of forcings***.

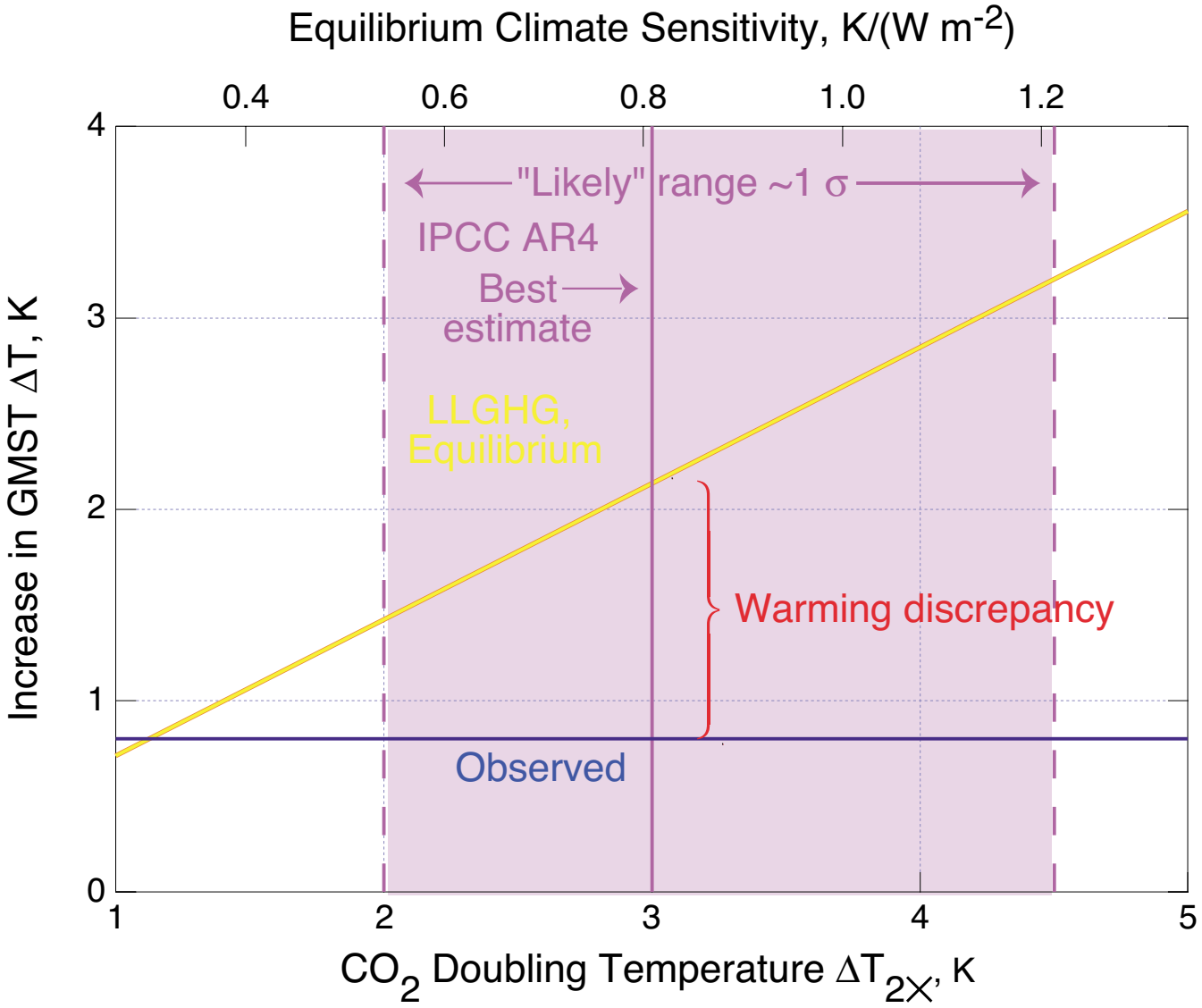
IPCC AR4, 2007

How can this be?

THE WARMING DISCREPANCY

EXPECTED INCREASE IN GLOBAL TEMPERATURE

Long-lived GHGs only – Dependence on climate sensitivity

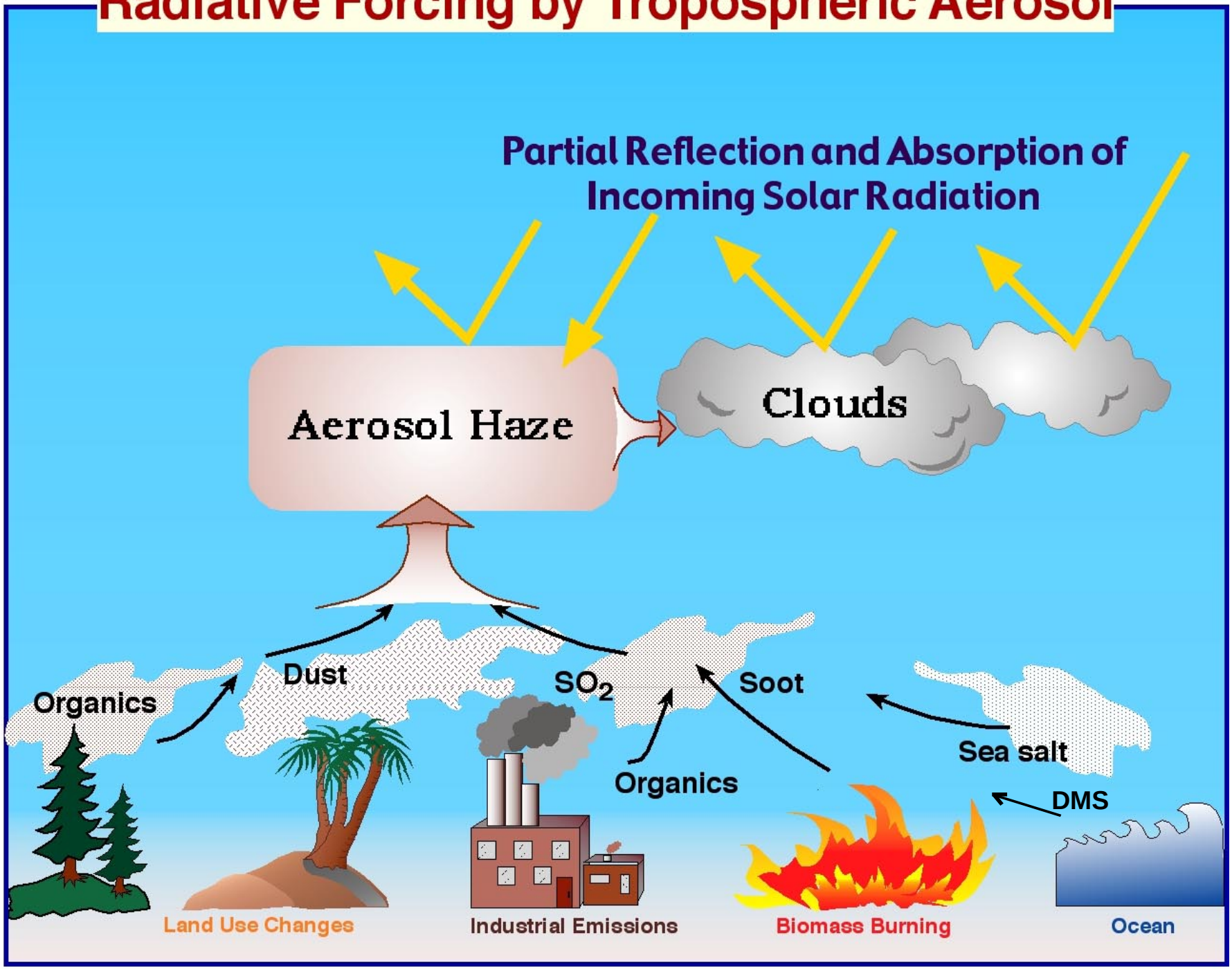


This discrepancy holds throughout the IPCC AR4 "likely" range for climate sensitivity.

Schwartz et al. J. Climate, in press, 2010

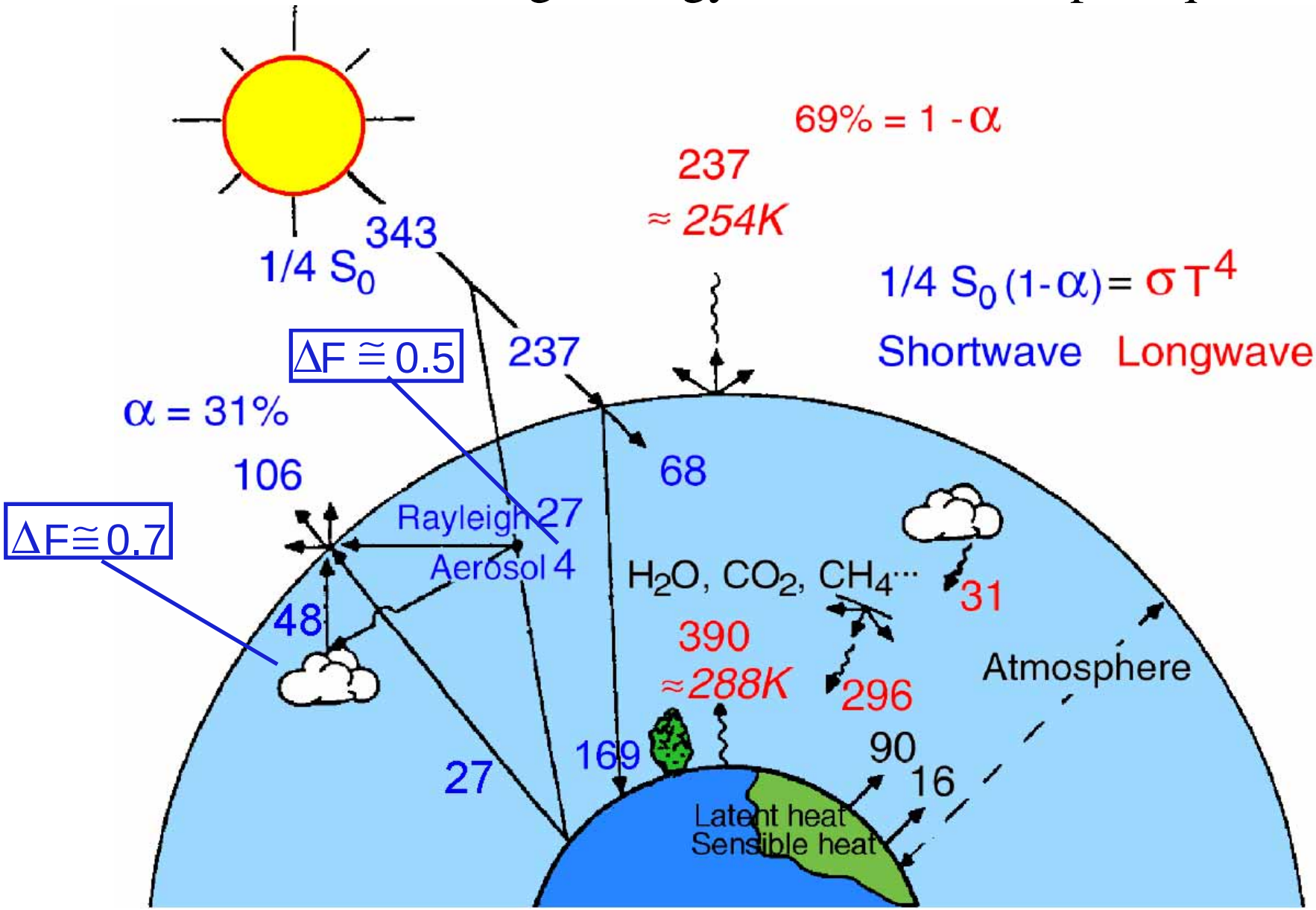
AEROSOL FORCING AND IMPLICATIONS

Radiative Forcing by Tropospheric Aerosol



GLOBAL ENERGY BALANCE

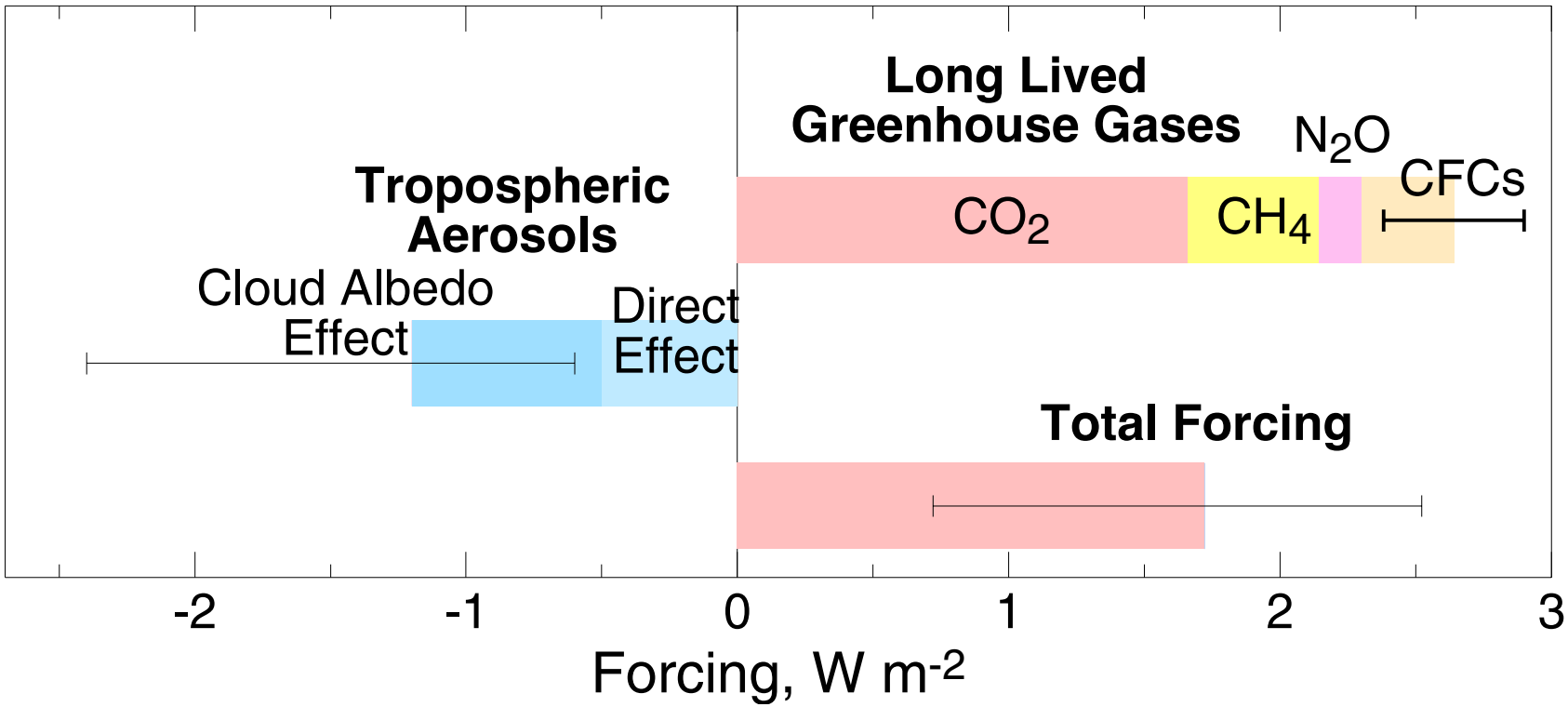
Global and annual average energy fluxes in watts per square meter



Schwartz, 1996, modified from Ramanathan, 1987

CLIMATE FORCINGS OVER THE INDUSTRIAL PERIOD

Extracted from IPCC AR4 (2007)



Total forcing includes other anthropogenic and natural (solar) forcings.

Forcing by tropospheric ozone, ~0.35 W m^{-2}, is the greatest of these.

Uncertainty in aerosol forcing dominates uncertainty in total forcing.

RESOLUTION OF THE WARMING DISCREPANCY

The warming discrepancy can be resolved by some combination of aerosol forcing and/or climate sensitivity lower than the IPCC central value.

Because of uncertainty in aerosol forcing the resolution cannot now be apportioned between these two causes.

This situation results in major uncertainties in future energy strategies.

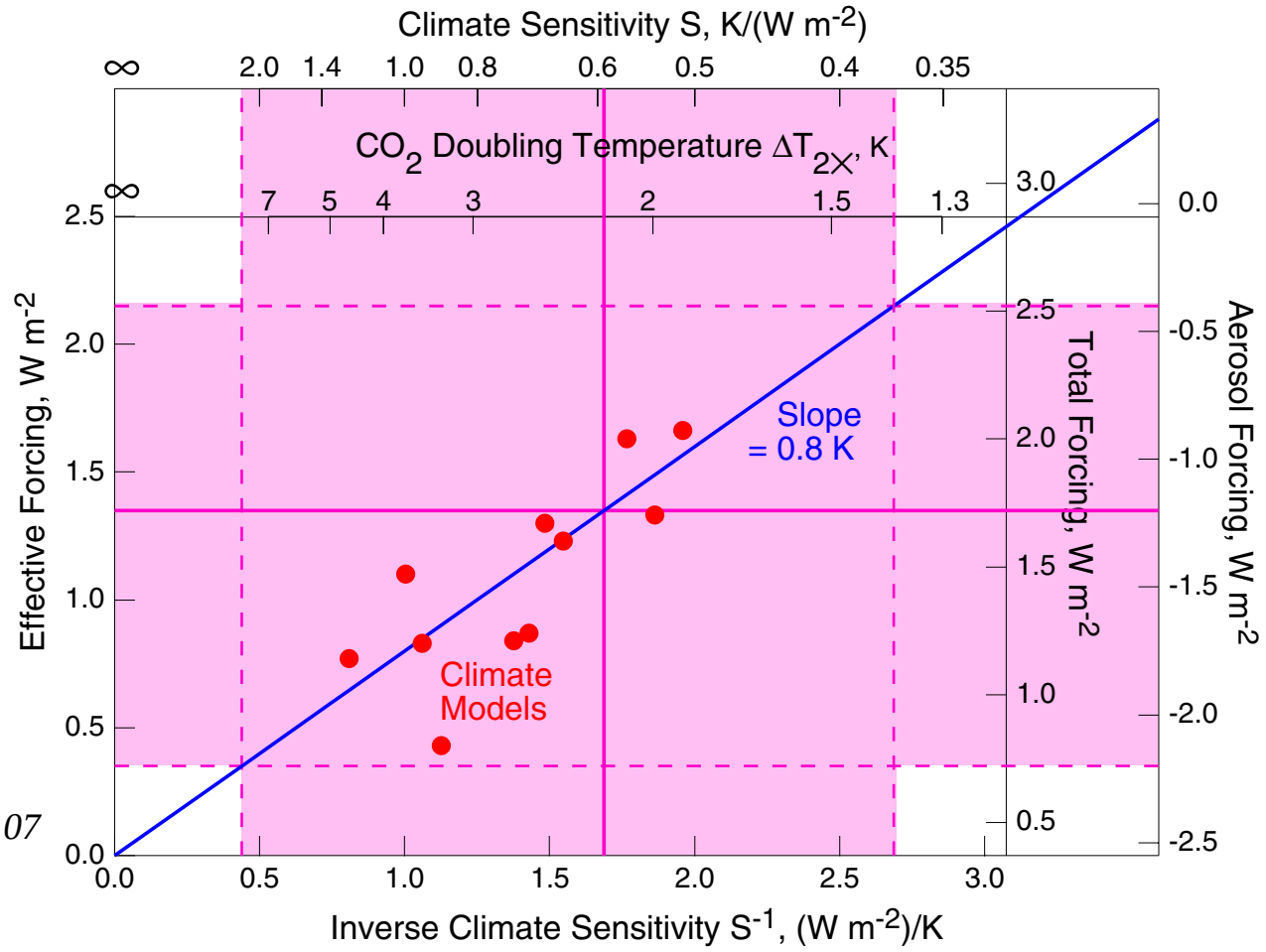
CLIMATE MODEL DETERMINATION OF CLIMATE SENSITIVITY

Effect of uncertainty in forcing

$$F_{\text{eff}} = F - H$$

$$\Delta T = SF_{\text{eff}}$$

$$F_{\text{eff}} = \Delta T S^{-1}$$



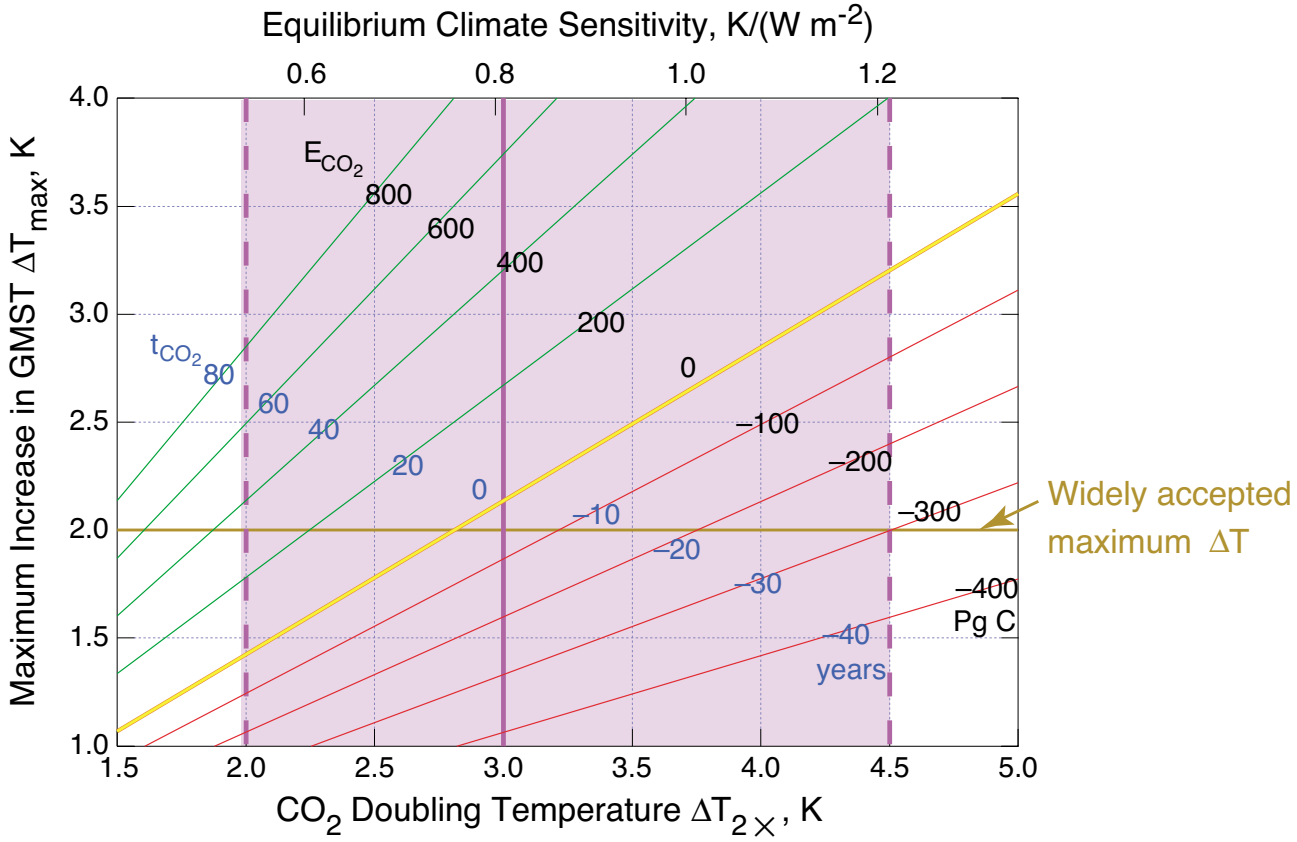
Model sensitivities and forcings from Kiehl, GRL, 07

Uncertainty in aerosol forcing allows climate models with widely differing sensitivities to reproduce temperature increase over industrial period.

ALLOWABLE FUTURE CO_2 EMISSIONS CALCULATED WITH A SIMPLE CARBON BUDGET MODEL

ALLOWABLE FUTURE CO_2 EMISSIONS

Dependence on climate sensitivity and acceptable increase in temperature relative to preindustrial



For $\Delta T_{max} = 2$ K . . .

If sensitivity $\Delta T_{2\times}$ is 3 K, ***no more emissions***.

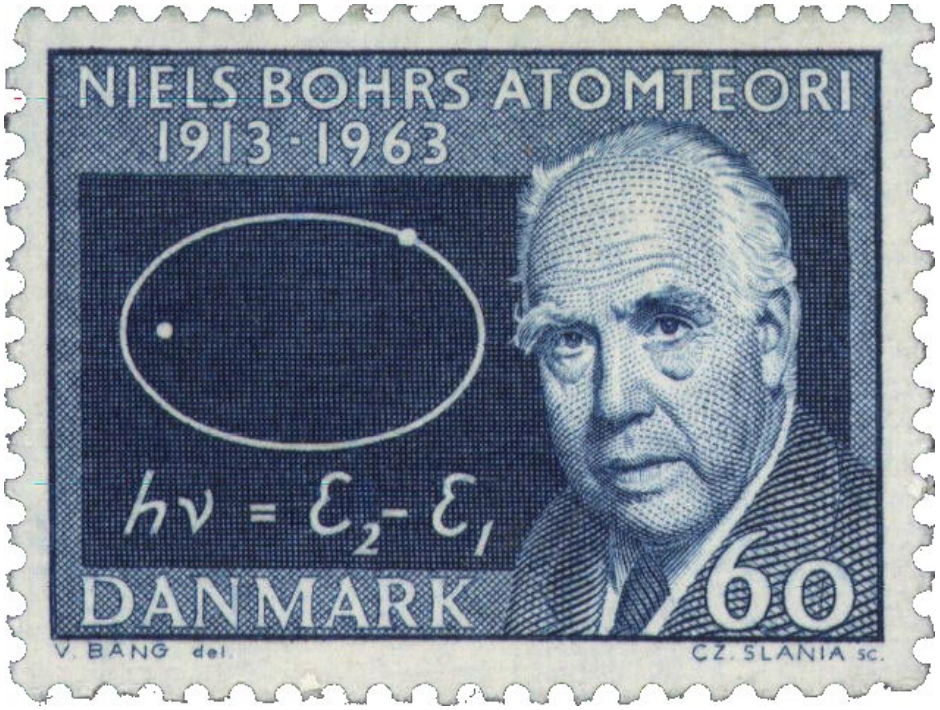
If sensitivity $\Delta T_{2\times}$ is 2 K, ~ ***30 more years of emissions at present rate***.

If sensitivity $\Delta T_{2\times}$ is 4.5 K, ***threshold is exceeded by ~30 years***.

Schwartz et al. J. Climate, in press, 2010

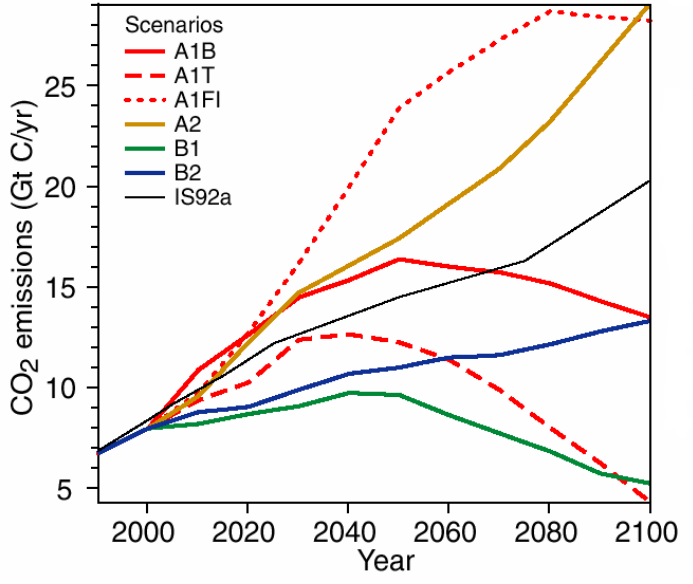
Looking to the Future . . .

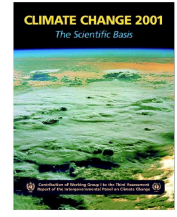
Prediction is difficult,
especially about the future.



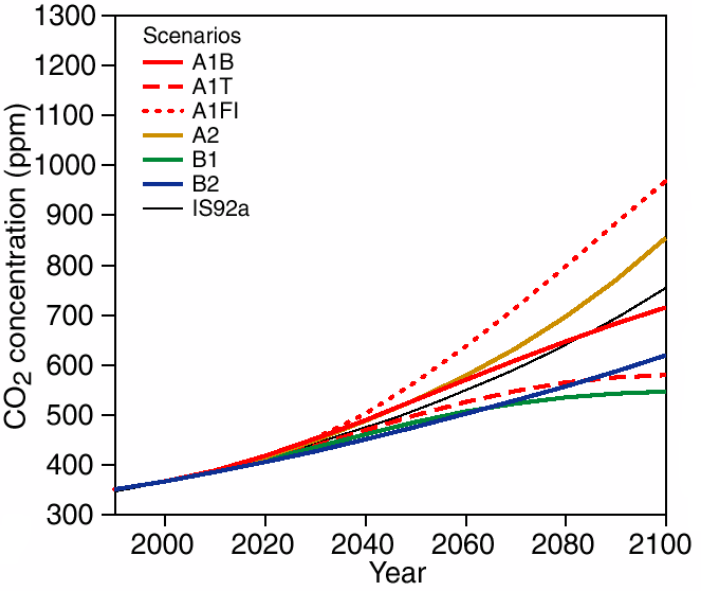
– Niels Bohr

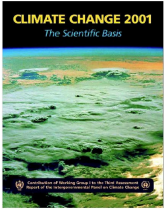
PROJECTIONS OF FUTURE CO2 EMISSIONS





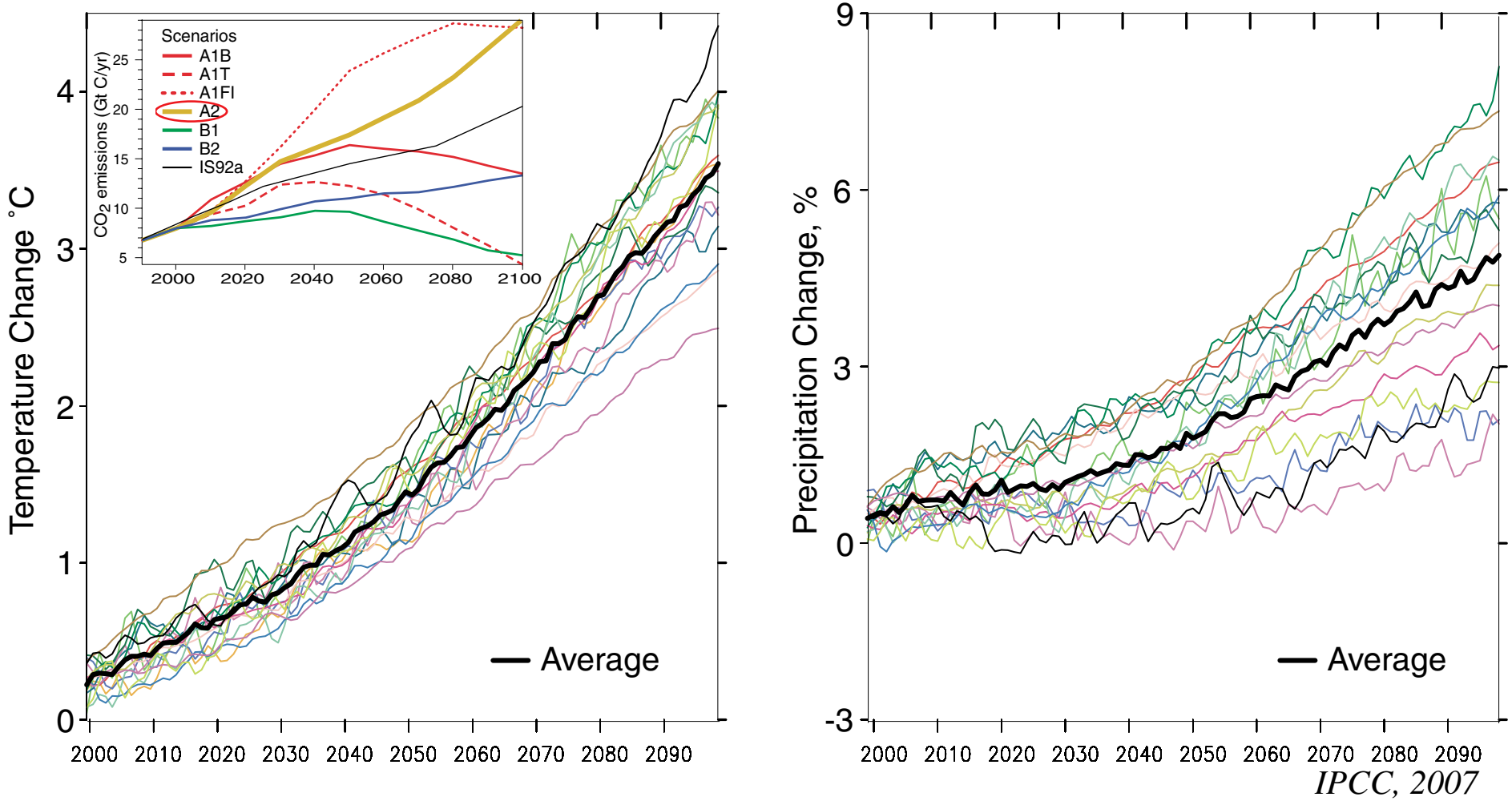
PROJECTIONS OF FUTURE CO2 CONCENTRATIONS





TWENTY-FIRST CENTURY CLIMATE CHANGE

Change in ***global*** temperature and precipitation for A2 emission scenario, relative to 1980-1999, calculated with 16 GCMs

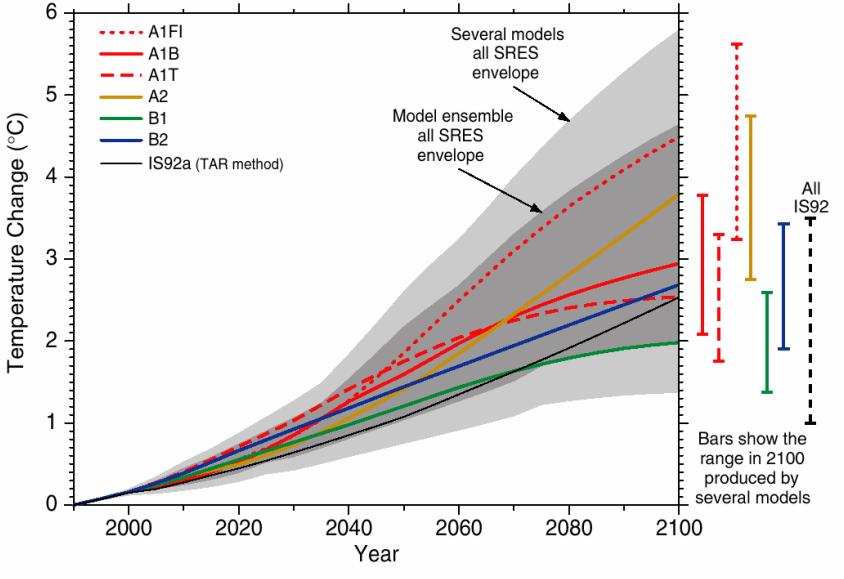


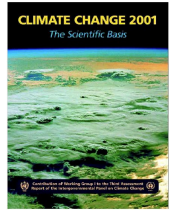
IPCC, 2007

Models agree that ***global temperature and precipitation increase with increasing CO_2***.

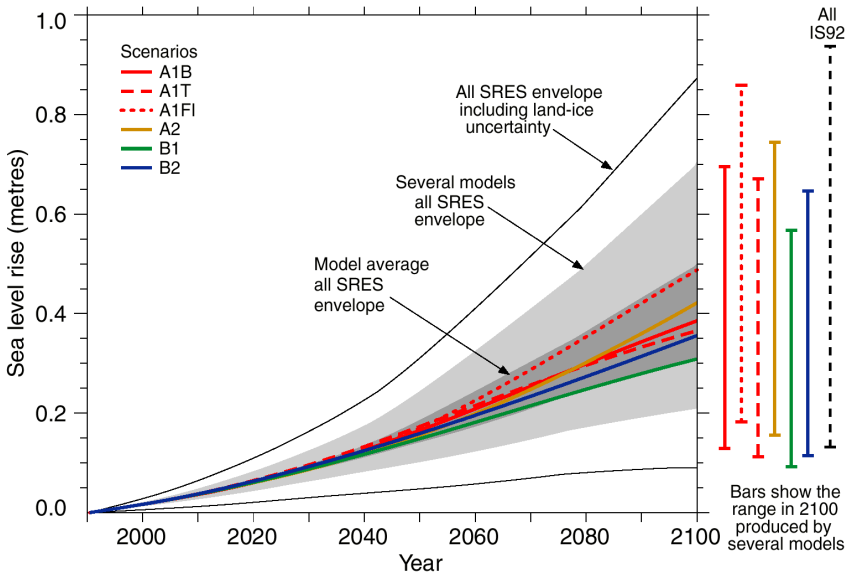
Projected increases exhibit ***large inter-model variation***.

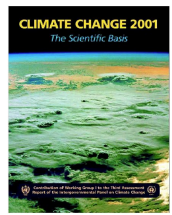
PROJECTIONS OF FUTURE TEMPERATURE CHANGE





PROJECTIONS OF FUTURE SEA LEVEL RISE



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RHODE ISLAND
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Philadelphia
New York City
Wilmington
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MARYLAND
Camden
NEW JERSEY
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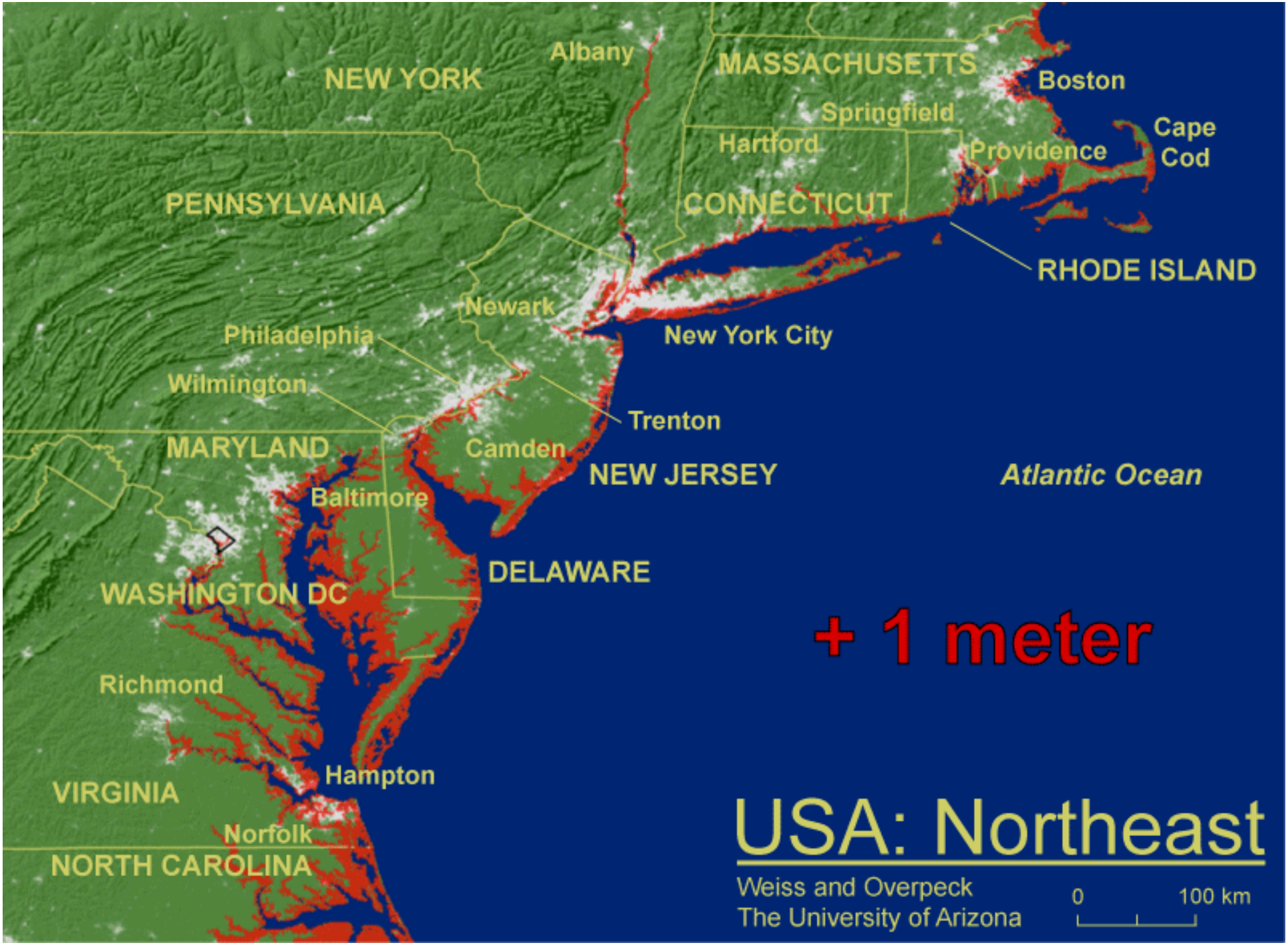
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Baltimore
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WASHINGTON DC
+ 1 meter
Richmond
Hampton
VIRGINIA
Norfolk
NORTH CAROLINA
USA: Northeast
Weiss and Overpeck
The University of Arizona
0
100 km

REGIONAL CLIMATE CHANGE

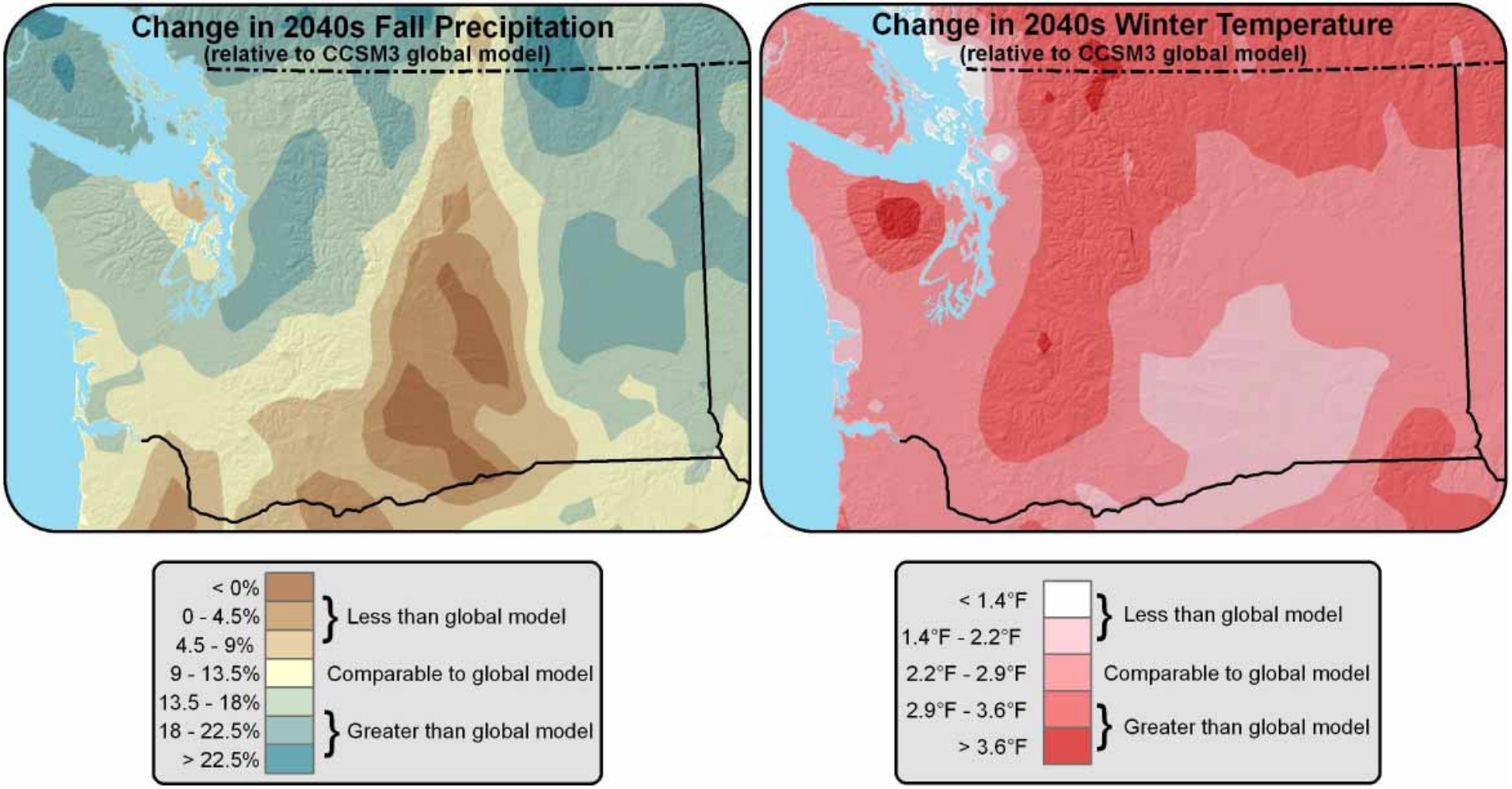
WHAT WILL BE THE FUTURE CLIMATE OF ILLINOIS?

It will be as if you move Illinois 200 miles south.

But we don't know if it will be moving to Georgia or the Texas panhandle.

REGIONAL CLIMATE CHANGE

Changes in Fall Precipitation and Winter Temperature in Washington State



Washington Climate Impacts Assessment, 2009

Quantity shown is difference between regional and global climate model.

BEWARE OF HIGHLY SPECIFIC PROJECTIONS

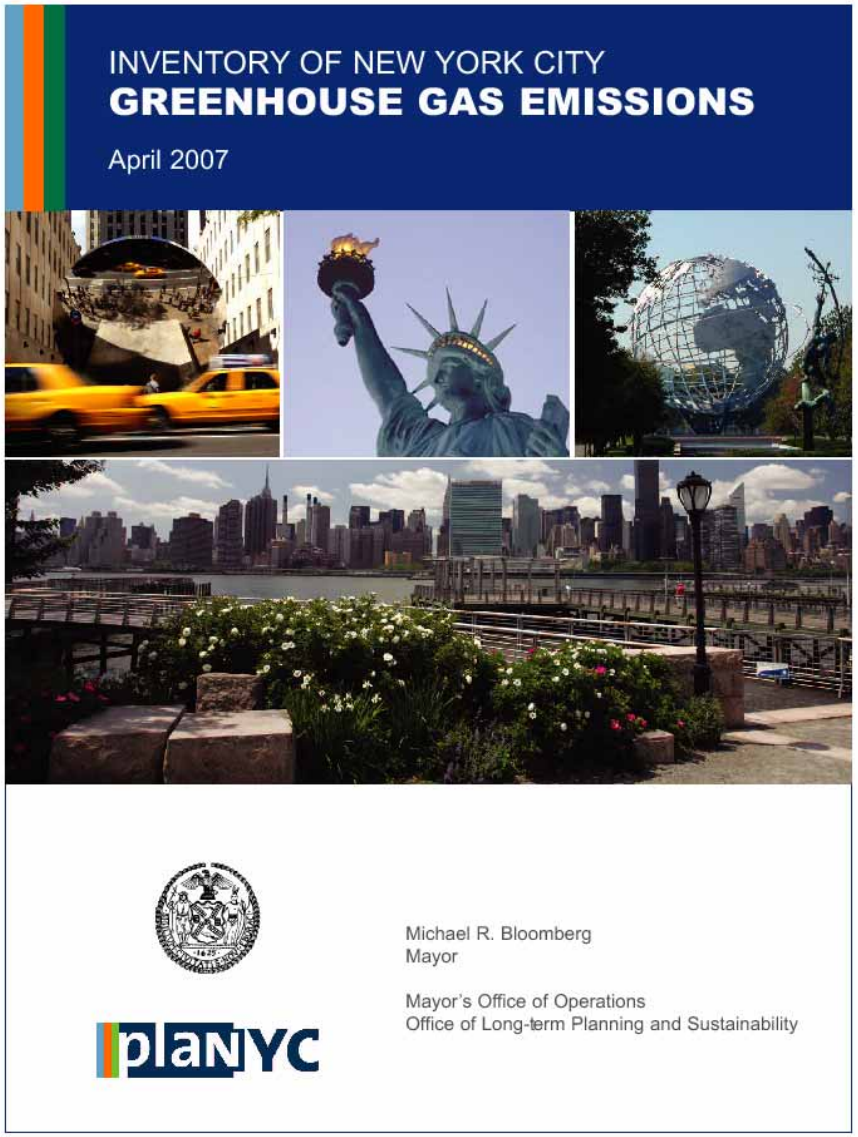
- ***Human health***: ***Under medium warming scenarios***, more people are projected to die because of heat waves. In King County, for example, it is projected that ***by 2025 there could be 101 additional deaths among people 45 and older; by 2045, there could be an additional 156 deaths***.
- ***Agriculture***: Impacts on Eastern Washington are not projected to be severe for the winter wheat, apples and potatoes through mid-century, ***assuming there is the same amount of water for irrigation and that more carbon dioxide in the atmosphere***, which plants use to grow, will prove beneficial. ***Yields of winter wheat, for instance, could increase about 8 percent during the 2020s and 20 percent during the 2040s***....Under the medium greenhouse-gas emission scenario, ***average apple and cherry yields could decline 20 to 25 percent in the 2020s***.

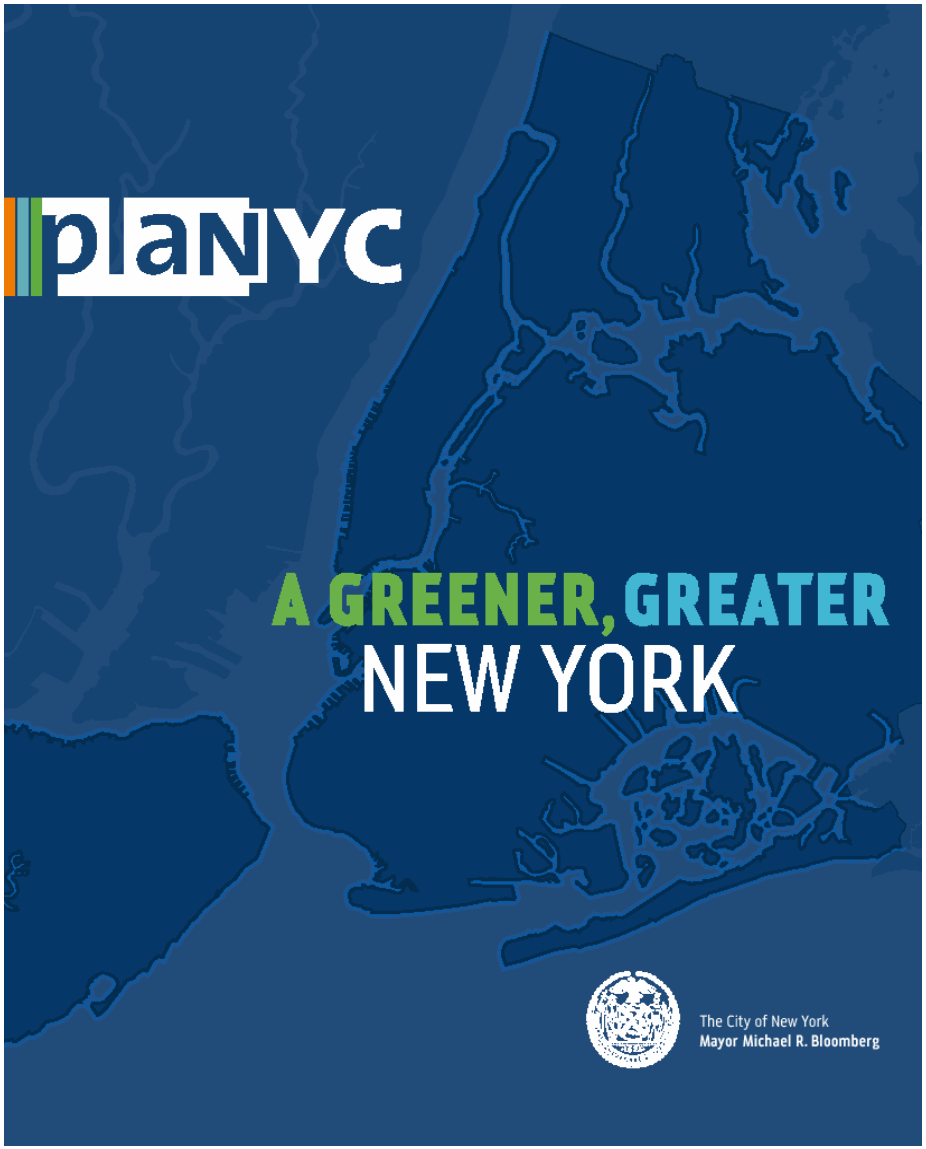
Washington Climate Impacts Assessment, 2009

WHAT CAN WE DO IN MY STATE?

NEW YORK CITY AS EXAMPLE

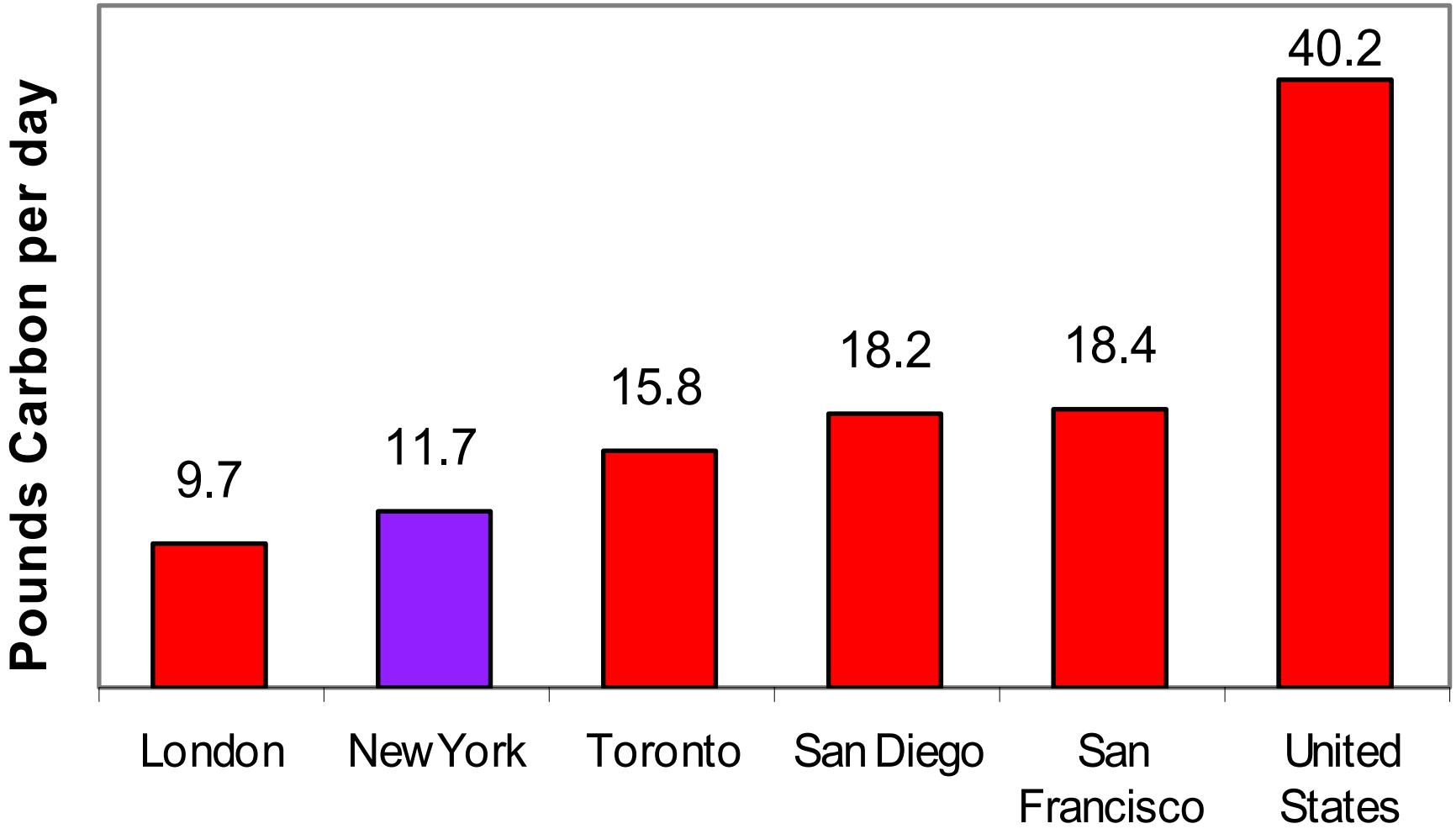
Survey of emissions and plan to reduce emissions 30% by 2030





CARBON DIOXIDE EMISSIONS IN SELECTED CITIES

Pounds of carbon per person per day



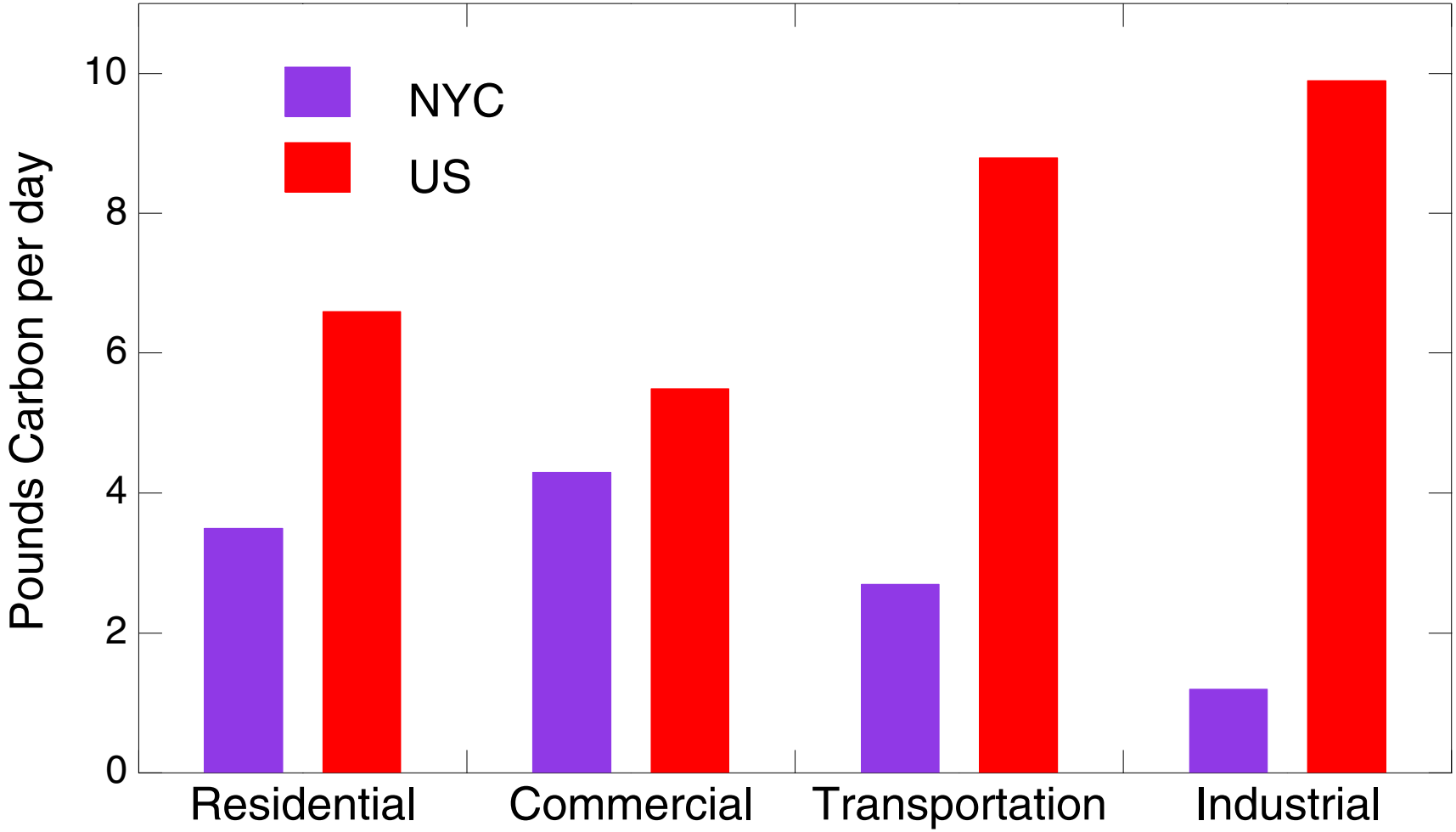
New York City Greenhouse Gas Emissions, April, 2007

Cities are energy efficient.

CARBON DIOXIDE EMISSIONS BY SECTOR

Comparison of New York City vs. United States Average

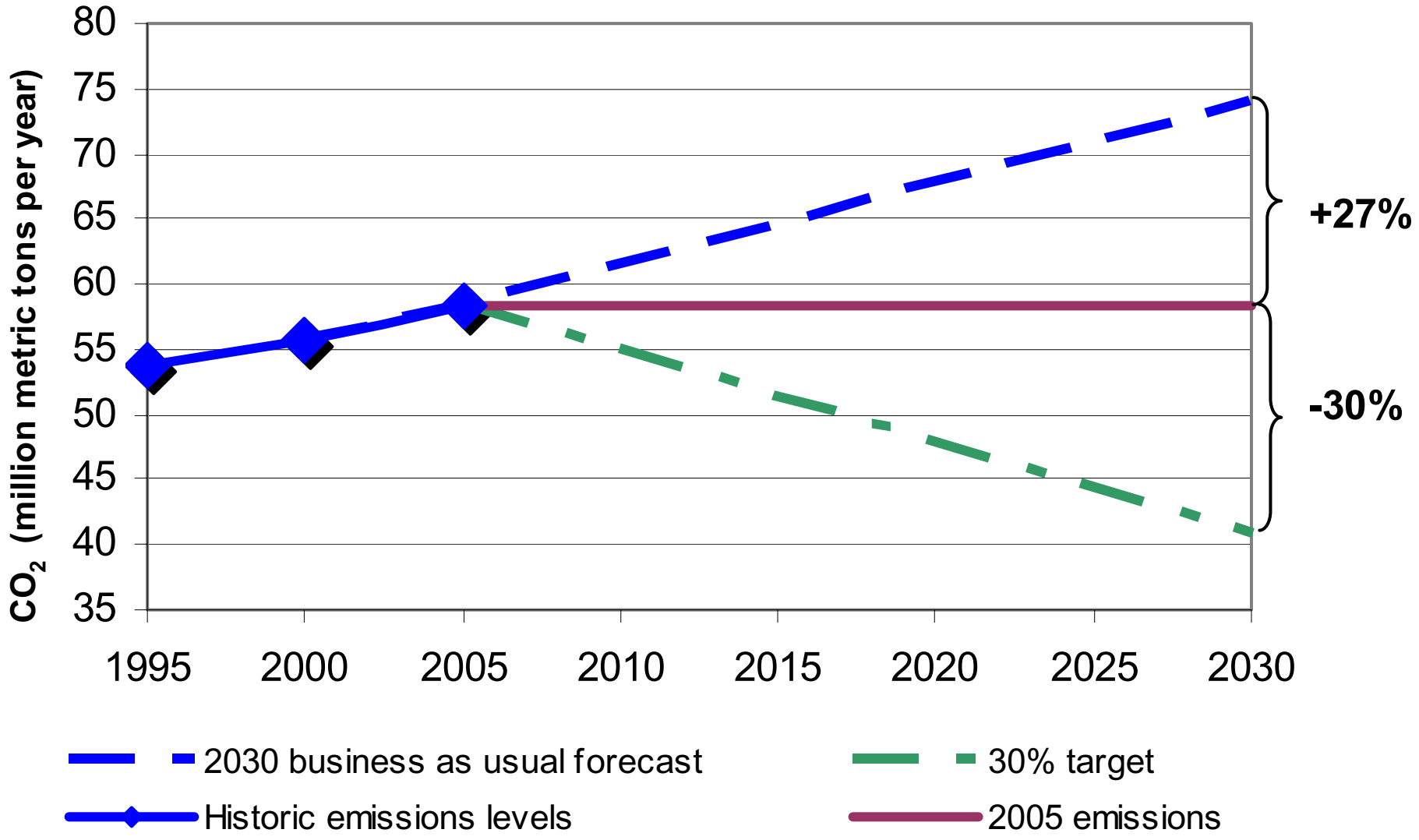
Pounds of carbon per person per day



New York City, EPA

PROJECTED CARBON DIOXIDE EMISSIONS FOR NEW YORK CITY

2005 - 2030



New York City Greenhouse Gas Emissions, April, 2007

TAKE HOME MESSAGES

Much about Earth's climate is quite well understood, but climate change is a ***really tough scientific problem***, and ***important, first order questions are poorly constrained***.

Climate change due to increased CO_2 could be ***serious to severe to catastrophic***, not on the time scale of re-election, but on the time scale of generations.

What will climate change do to my state?

Illinois as example.

What can we do about climate change in my state?

New York City as example.

Actions that we take now are of long consequence.

The lifetime of incremental atmospheric CO_2 is about 100 years.

The expected life of a new power plant is 50 to 75 years.